AFFDL-TR-73-50
Volume III

ADVANCED METALLIC STRUCTURES: AIR SUPERIORITY FIGHTER WING DESIGN FOR IMPROVED COST, WEIGHT AND INTEGRITY

VOLUME III STRESS, FATIGUE AND FRACTURE, COST AND MATERIAL DATA

D. F. Davis, et al.

GENERAL DYNAMICS
Convair Aerospace Division
Fort Worth Operation

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Air Force Flight Dynamics Laboratory
Air Force Systems Command
Wright Patterson Air Force Base, Ohio

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F O R E W O R D

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These studies were performed by the Structural Design Group, Convair Aerospace Division of General Dynamics, Fort Worth Operation with D. F. Davis as the Program Manager. Other principal participants in the program are as follows: R. W. McAnally, Structural Design; E. W. Gomez, Stress Analysis; J. W. Morrow, Fatigue and Fracture Analysis; J. M. Shults, Materials Engineering; T. E. Henderson, Mass Properties; J. D. Jackson, Value Engineering; J. L. McDaniel, Manufacturing Engineering; B. G. W. Yee, Nondestructive Inspection; D. Duncan, Quality Assurance; H. E. Bratton, Information Transfer; and R. L. Jones, Engineering Test Laboratory.

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This report has been reviewed and is approved.

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A B S T R A C T

This report describes the preliminary design and analysis for an Advanced Air Superiority Fighter Stores Loaded, Wet Wing Structure. The wing box of the F-111F airplane designed by the Convair Aerospace Division of General Dynamics was used as the baseline vehicle.

A unique design methodology was followed to arrive at three configurations which offer an optimum balance between structural efficiency and technological advancement. This methodology consists of compiling element concepts; integrating them into cross-section drawings; optimizing them in analytical assemblies; and finally preparing full wing box designs. Each step was followed with a detailed evaluation and ranking step which utilized a formal merit rating system. This system permitted the evaluation of numerous concepts and insured that each technical discipline participated in the design selection.

A subsequent program is proposed to evaluate the capability of the selected design to meet the overall program goals of advancing technology without significantly affecting costs. The subsequent program involves additional preliminary design, a development test program, detail design, manufacture, and tests; including static, fatigue, and damage tolerance testing. Information generated during this effort will be disseminated to the Air Force and industry in general through an intensive information transfer effort.

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STRESS ANALYSIS

V.1 FLIGHT TEST WING LOADS

This section presents the portion of results of the flight loads buildup and demonstration tests for the F-111 with no external stores as applicable to the F-111F wing. The entire test program results are reported in Reference 1. These balanced symmetric flight tests were accomplished on F-111A No. 13 and F-111A No. 75. These tests were accomplished to establish the maximum load levels encountered in flight. The ultimate objective of such testing is to show that the loads used for design and the loads applied in static test are adequate.

V.1.1 Background

The initial flight loads program for the F-111 is outlined in Reference 2. It was developed to meet MIL-S-5711 requirements for a flight loads survey and demonstration. Flight testing, based on that program, began in July 1967 and continued through February 1968. At that time, the test airplane (F-111A No. 13) went into down-time for extensive structural rework to bring it up to the production configuration.

In November 1968, during the "F-111A/E/D Structural Integrity Reconsideration Meeting" at the SPO, General Dynamics was directed to reduce program costs by realigning the structural integrity flight program. The new program was to be a build-up demonstration in lieu of the Flight Loads Survey and Demonstration. An analytical survey rather than a flight loads survey would be relied on to define load trends and to select critical maneuvers and wing sweeps for demonstration. A few noncritical conditions were to be flown to verify the analysis which led to the prediction of critical conditions. The SPO position was that sufficiently accurate loads can be derived less expensively on the ground. The flight program is then aimed at proving the loads for the predicted critical conditions are no greater than those used for design.

At that time, General Dynamics was "tooling-up" for a complete F-111D analytical loads survey. It was to be based on all available F-111 wind tunnel data and would contain a complete set of basic aerodynamic coefficients along with matching airload distributions. The inertia data used would

also include matching panel point distributions so that final net loads would result in a "balanced airplane" for each condition analyzed. The net load trends resulting from such an analysis would provide the analytical baseline desired for establishing the new flight loads program. This analytical loads survey, although specifically being conducted for the F-111D, would be directly applicable to the F-111A for the purpose of selecting demonstration, validation, and build-up conditions. Thus the new program definition is based on F-111D maneuver analysis load trends supplemented by data gathered during the early flight loads survey.

The initial phase flight loads survey results and the F-111D analytical predictions show that balanced symmetric maneuvers develop the maximum load magnitudes on the wing and high lift devices. The survey results supplemented by the analytical predictions were the basis for selection of test points for these components. Demonstration maneuvers were flown at the predicted critical conditions to define peak load magnitudes. In addition, several non-demonstration (lower load level validation type) maneuvers were performed at different points to confirm that the maneuvers selected for demonstration are at the critical conditions. Table I shows a summary of the balanced symmetric maneuver critical conditions.

V.1.2 Flight Loads

A discussion of flight loads is presented in the following paragraphs.

V.1.2.1 Loads Measurement Methods

Flight loads data on the F-111 aircraft are acquired by means of calibrated strain gauge bridges installed on the wing, fuselage, and vertical and horizontal tails. Shear, bending moment, and torsion are measured at four spanwise stations on the right-hand wing outer panel and at the right-hand and left-hand pivot center line by means of instrumentation installed on the pivot support structure as illustrated in Figure 1. All strain gauge bridges are located in such a manner to provide the required measurement accuracy with minimum effect due to concentrated load effects, stress concentrations, or thermal strains. Prior to instrumenting the flight test wing, a development test was conducted in which a stub wing specimen was instrumented and loaded at both room temperature and transient heating conditions to verify the

Table I

SUMMARY OF BALANCED SYMMETRIC MANEUVER CRITICAL CONDITIONS AND COMPONENTS

COND.	Λ	MACH	ALT	n_zW	COMPONENT LOAD ENVELOPE DEFINED BY CONDITION
F101A	16	330 KCAS	S.L.	320,000	Wing Torsion, Flap Track Loads
		277 KCAS	S.L.	320,000	Slat Track Loads
F201A	26	0.88	S.L.	533,000	Pivot and Inboard Wing Shear
F300A	35	0.93	S.L.	533,000	Wing - Inboard Shear Fwd Fus - Shear and Moment, Aft Fus - Shear
F304A	35	0.85	S.L.	-218,300	Wing-Pivot & Inboard Shear, Carry-thru Box Moments Fwd. Fus - Shear and Moment; Aft Fus - Shear
F400A	45	1.05	2,000	533,000	Wing - Moment and Outboard Shear Aft Fus. - Shear and Moment
F401A	45	1.05	8,000	-218,300	Wing - Mid Span Shear, Pivot & Inb'd Wing Moment Fwd. Fus. Shear; Aft Fus - Shear & Moment
F410	45	1.05	4,500	533,000	Aft Fus. Shear and Moment
F501A	50	1.05	S.L.	533,000	
F600	60	1.40	17,500	533,000	Carry Thru Box Moments Fwd. Fus - Shear & Moment; Aft Fus. Shear and Moment
F701A	72.5	1.40	17,500	533,000	
F702A	72.5	1.40	17,500	-218,300	Wing - Torsion, Tip Shear & Moment Fwd Fus.- Shear & Moment; Aft Fus - Shear and Moment

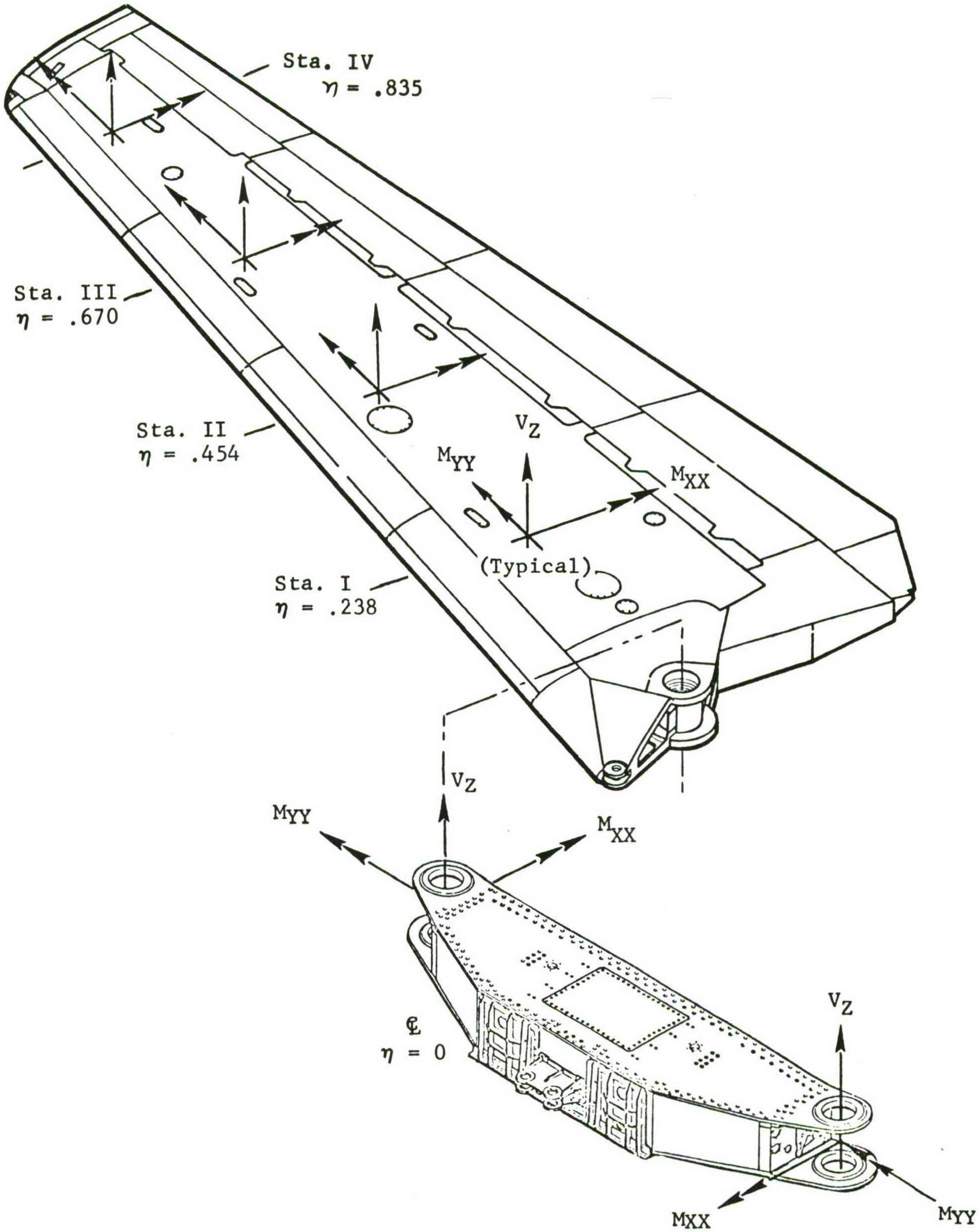


Figure 1 F-111 Wing Loads Measurements

absence of temperature effects. Analytical studies were also made to establish that fuel pressurization effects would not degrade the wing load measurements. Strain gauges are also installed on all support fittings of high-lift and spoiler systems to measure the concentrated load introduced at these points. A complete description of the strain gauge instrumentation on the F-111A flight loads aircraft is contained in Reference 3.

The strain gauge bridges were calibrated, loads equations derived, and individual bridges electrically combined to yield direct measurement of shear, moment, and torsion based upon the methods of Reference 4. It was found advantageous to calibrate the outer wing panel and the pivot support structure individually in separate test fixtures. This method was found to be practical because, with the determinate nature of the load reaction at the pivot, precise simulation of the support stiffness was not required to produce valid results and considerable flexibility in scheduling was obtained. The validity of the separated component calibration has been demonstrated in two ways:

1. The outer panel measured shears were integrated and compared with the measured bending moment distribution. These, together with outer panel torsion, were extrapolated to the pivot and compared with the measured pivot shear, moment and torsion. Agreement has been excellent for all wing sweeps.

2. Wing outer panel and pivot loads instrumentation was recorded during the recent structural proof tests of the aircraft and compared with the applied loads. Again, excellent agreement was obtained.

A complete description of the F-111A loads calibration methods and results is contained in References 5 and 6.

V.1.2.2 <u>Data Processing and Analysis</u>

Flight loads data for the F-111 were recorded on airborne magnetic tape utilizing FM/FM multiplexing techniques with standard IRIG subcarrier bands. In addition to the structural loads measurements, standard correlation items such as accelerations, positions, aircraft attitude, airspeed, and altitude were also recorded. Critical items of

information were telemetered to the ground control station for real-time monitoring and test evaluation by test engineers.

After flight, the data is converted to digital format and operated upon through General Dynamics prepared digital computer programs to apply calibration factors, inertia distributions, etc. The data is then presented directly in engineering units in both tabular form and as cross plots of load vs parameter using the Stromberg-Carlson 4020 Computer Recorder.

Included in the digital computer plotted output are plots of wing load normalized with altitude (load per unit dynamic pressure q) versus n_zW/q (normal load factor times gross weight per unit q). These plots are segregated according to wing sweep, configuration, maneuver type, Mach number and load parameter and contain load per q versus n_zW/q superimposed for all altitudes flown. The results are a definition of maximum load attained for each maneuver and a definition of aero-elastic effects on wing loads. Typical computer plots are shown in Figure 2 and Figure 3.

V.1.2.3 Maneuver Definitions

Several different types of maneuvers are accomplished during flight testing. A description of the two basic maneuvers used to accomplish wing loading is shown below:

Balanced symmetric maneuvers -

Normal symmetric pull up (NSPU) - A smooth pull up to a specified test load factor performed at a designated test speed and altitude. This maneuver is not intended to be abrupt except that it is performed with sufficient rapidity to minimize speed and altitude changes.

Normal symmetric push over (NSPO) - This is similar to the NSPU described above except that this NSPO maneuver is performed in the negative "G" direction by pushing over.

V.1.2.4 Flight Test Results

Flight measured loads confirm the analytical predictions of critical flight conditions. Maximum values developed from flight test results are all at or with design limits. Balanced

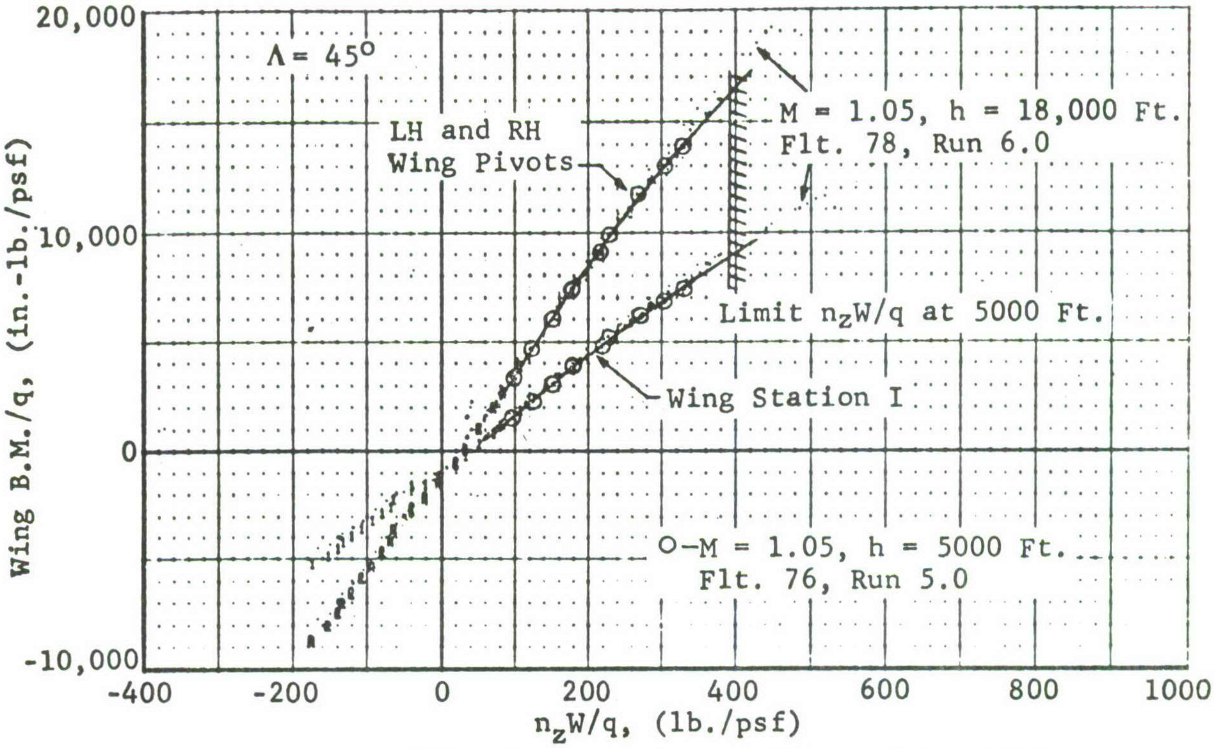


Figure 2 F-111 Wing B.M./q vs. nW/q — LH and RH Pivots and Wing Station I

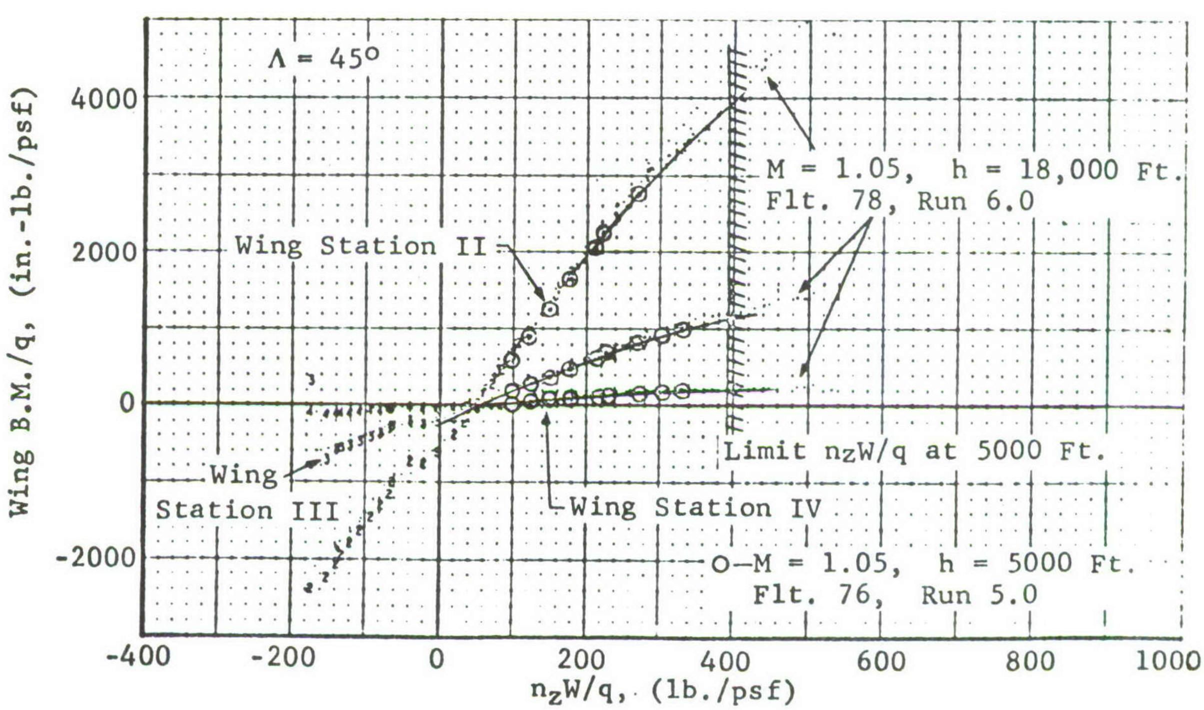


Figure 3 F-111 Wing B.M./q vs. nW/q — Wing Stations II, III and IV

airplane loads have been determined for the critical 16°, 26°, 35°, 45°, 50°, 60°, and 72° wing sweep conditions. The condition descriptions were summarized in Table I.

V.1.2.4.1 Wing. Flight data indicates wing loads smoothly decrease as the wings are swept aft at a given condition. Forward wing sweeps would develop higher maximum loads if they were not restricted to subsonic or transonic speeds at low altitudes. The decrease in wing loads with wing sweep is at least partially due to the fact that part of the wing slides into the fuselage as it is swept aft. Thus less of the wing is exposed to develop lift. The highest positive g loads over most of the moveable wing are developed at 45° wing sweep during a 1.05 Mach pullup to 533,000 n_zW. Condition F400A Table I. The highest negative g loads over most of the wing are developed at 45° during a 1.05 Mach pushover to -218,300 n_zW. Shear on the most inboard region is higher at 26° wing sweep and maximum torsion over the entire wing occurs when flaps are extended. Wing load distribution envelopes are shown in Figures 4 through 6.

Maximum torsion over the entire wing for negative g maneuvers is developed at 72° wing sweep. The same maneuver produces the highest shear and bending moment on the outboard section of the wing. The 45° wing sweep pushover is more critical for shear and bending over most of the rest of the wing although shear near the pivot is slightly higher at 35° wing sweep. Interaction diagrams at each instrumentation station for all test wing sweeps are provided in Figure 7 through 10.

V.1.2.4.2 High Lift Devices. Flap loads are primarily a function of flap deflection and dynamic pressure. Maximum values occur during a 16° wing sweep pullup to 320,000 n_zW at 330 KCAS with 30° flaps. The most critical flap track load is 90% of limit. Loads on each flap track at the rear spar, are summarized in Table II. A spanwise load distribution is provided in paragraph V.1.3.

Maximum positive g slat loads are also developed during a 16° wing sweep pullup to 320,000 n_zW with 30° flaps, but the critical speed is 277 KCAS. Slat loads are primarily a function of slat angle of attack and dynamic pressure. Peak loads occur when limit load factor and slat stall are reached simultaneously at the highest possible dynamic pressure. The load on the most critical slat, slat No. 3, is less than 86% of limit. Maximum values on each slat track are summarized in Table III.

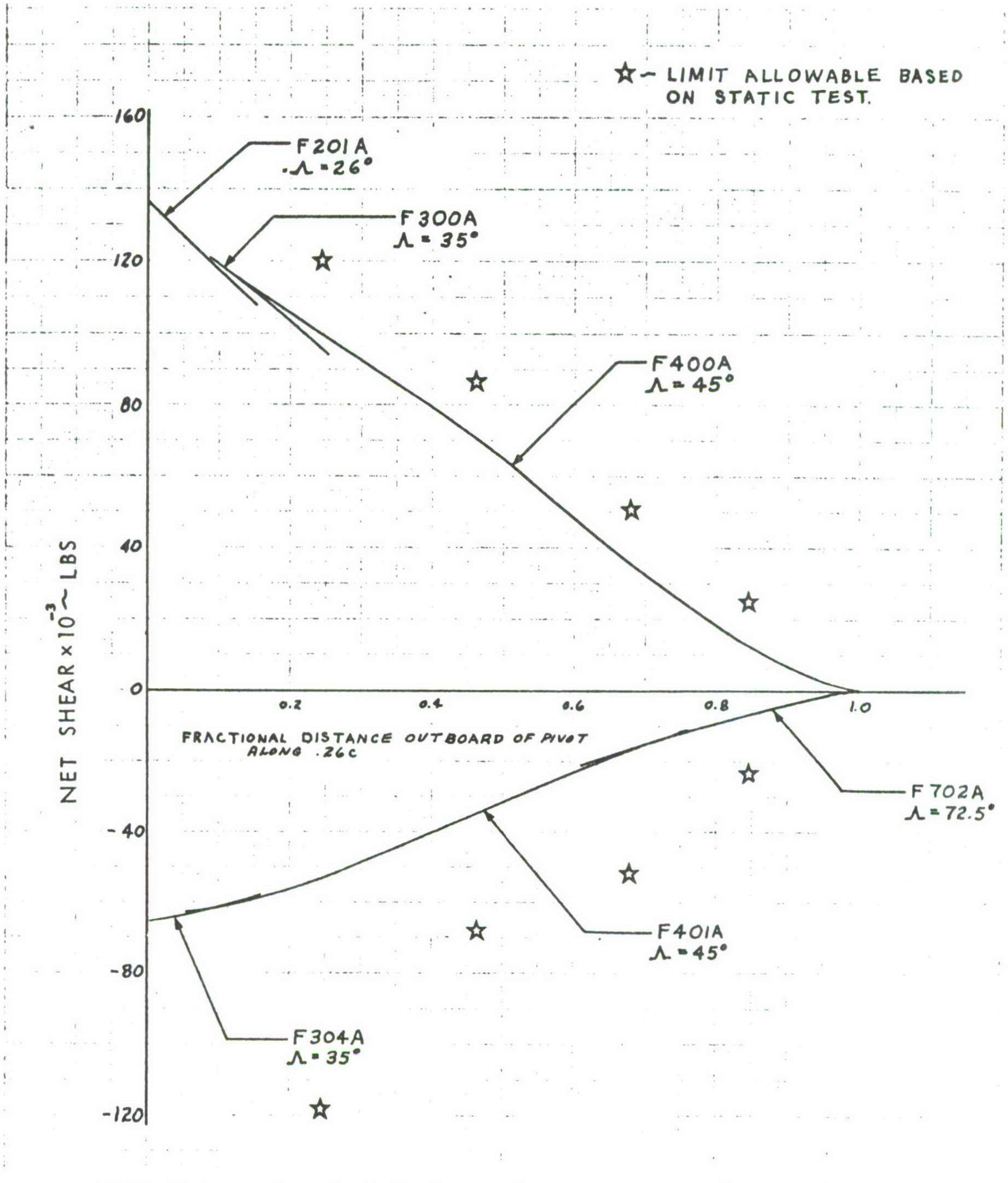


Figure 4 F-111 Net Wing Vertical Shear Envelop (Based on Flight Test Data)

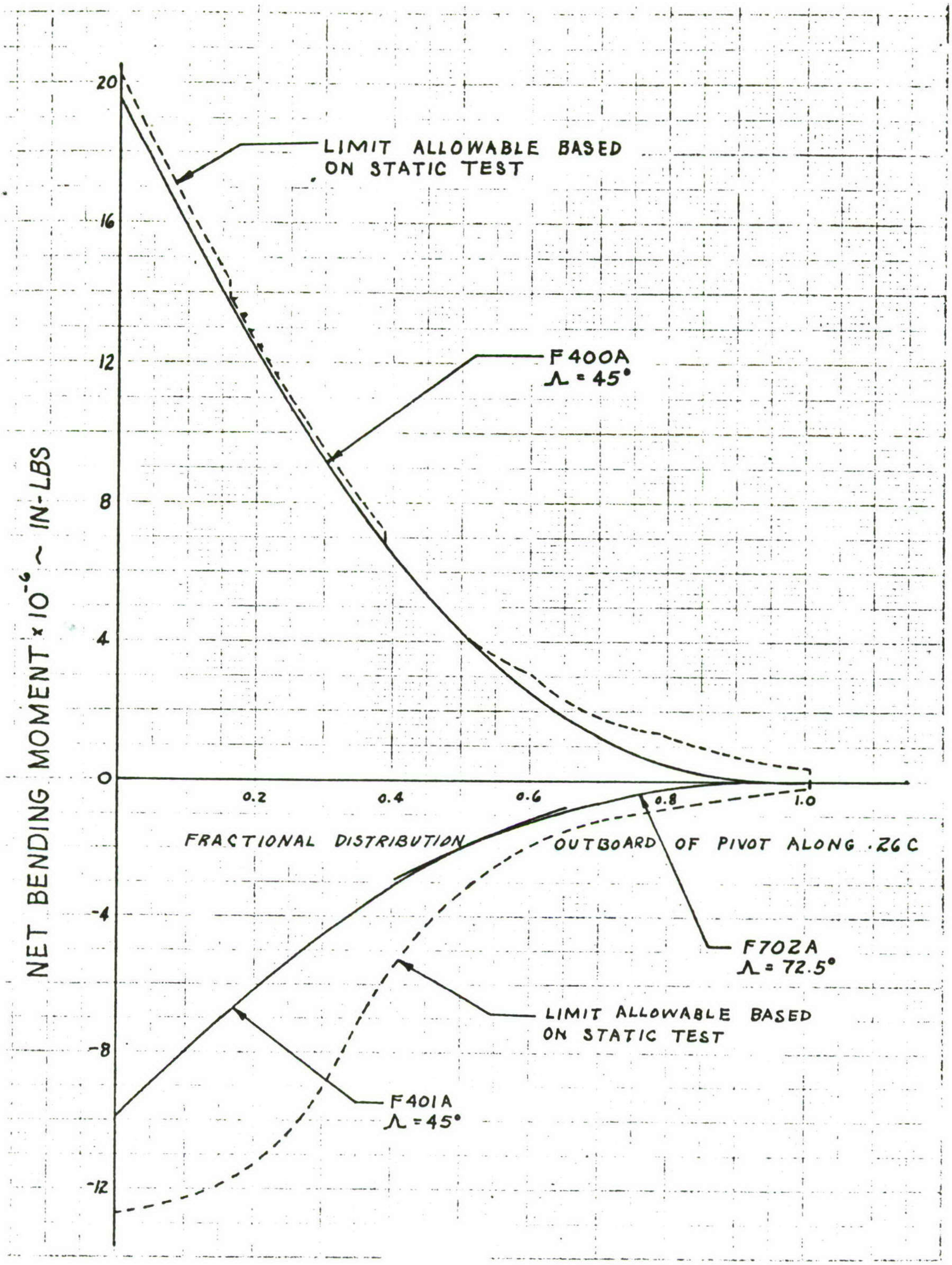


Figure 5 F-111 .26 Wing Chord Net Bending Moment Envelop (Based on Flight Test Data)

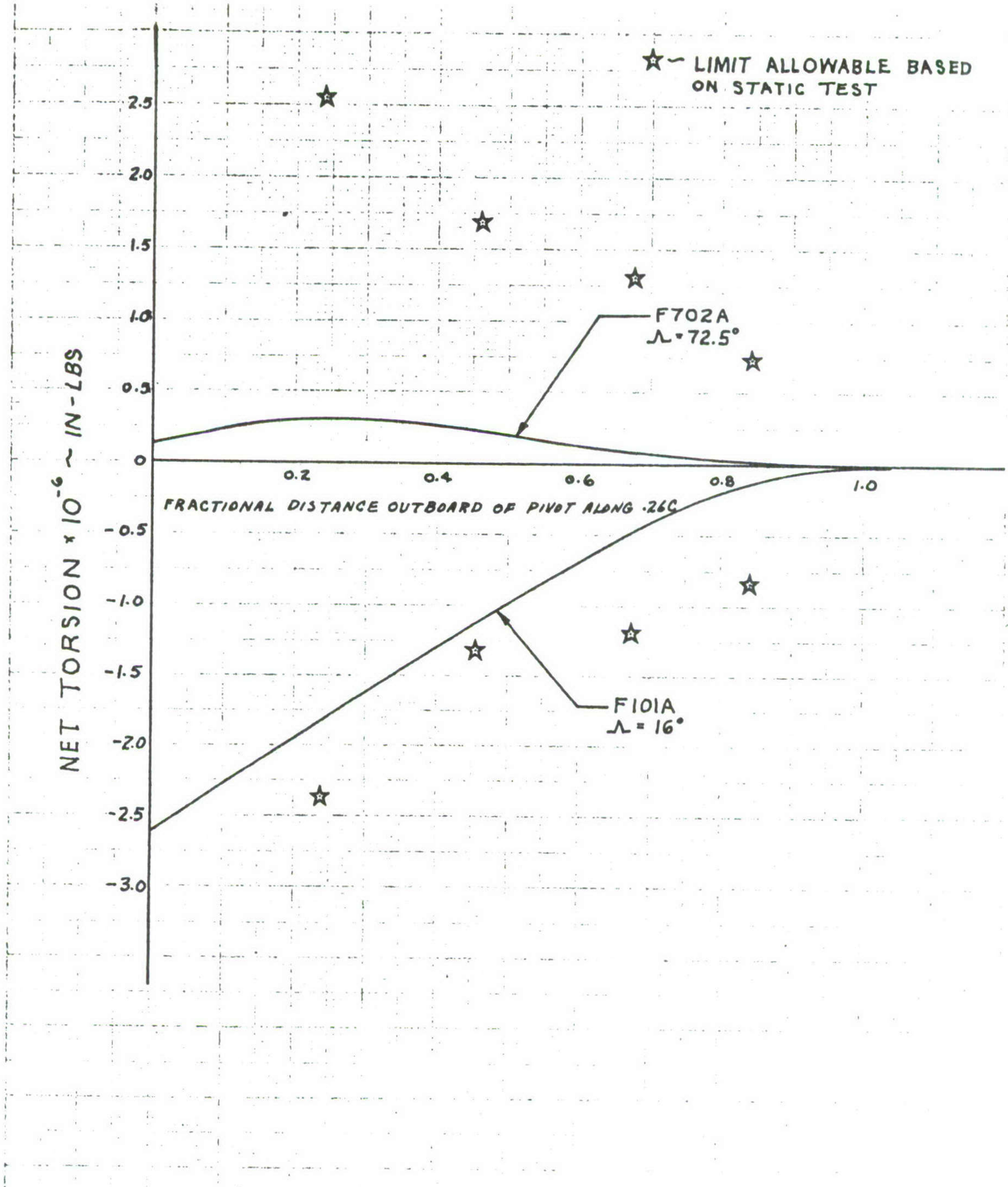


Figure 6 F-111 .26 Wing Chord Net Torsion Envelop (Based on Flight Test Data)

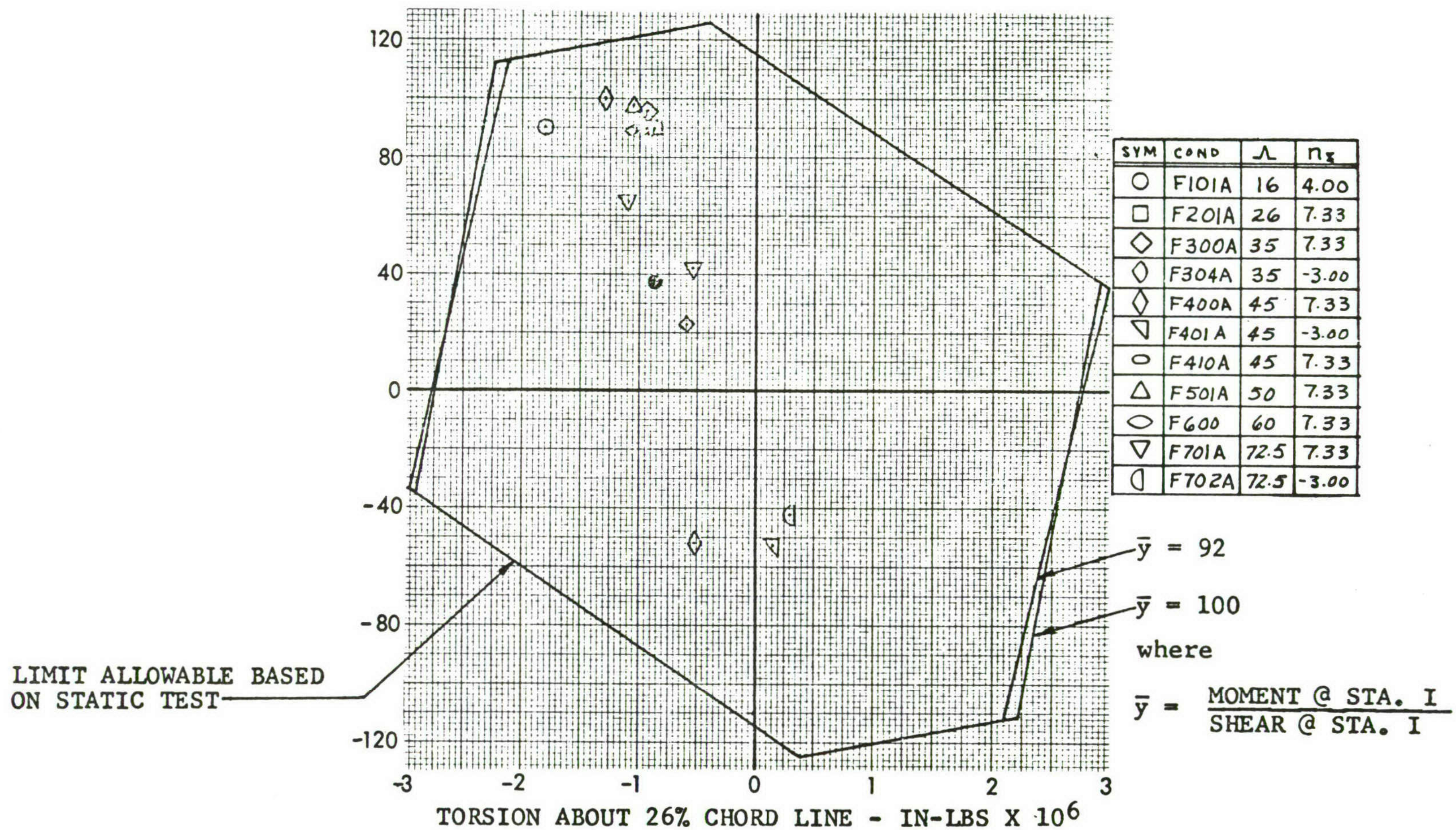


Figure 7

F-111 Wing Box Shear vs. Torsion - Station I
Summary of Balanced Symmetric Maneuver Final Loads

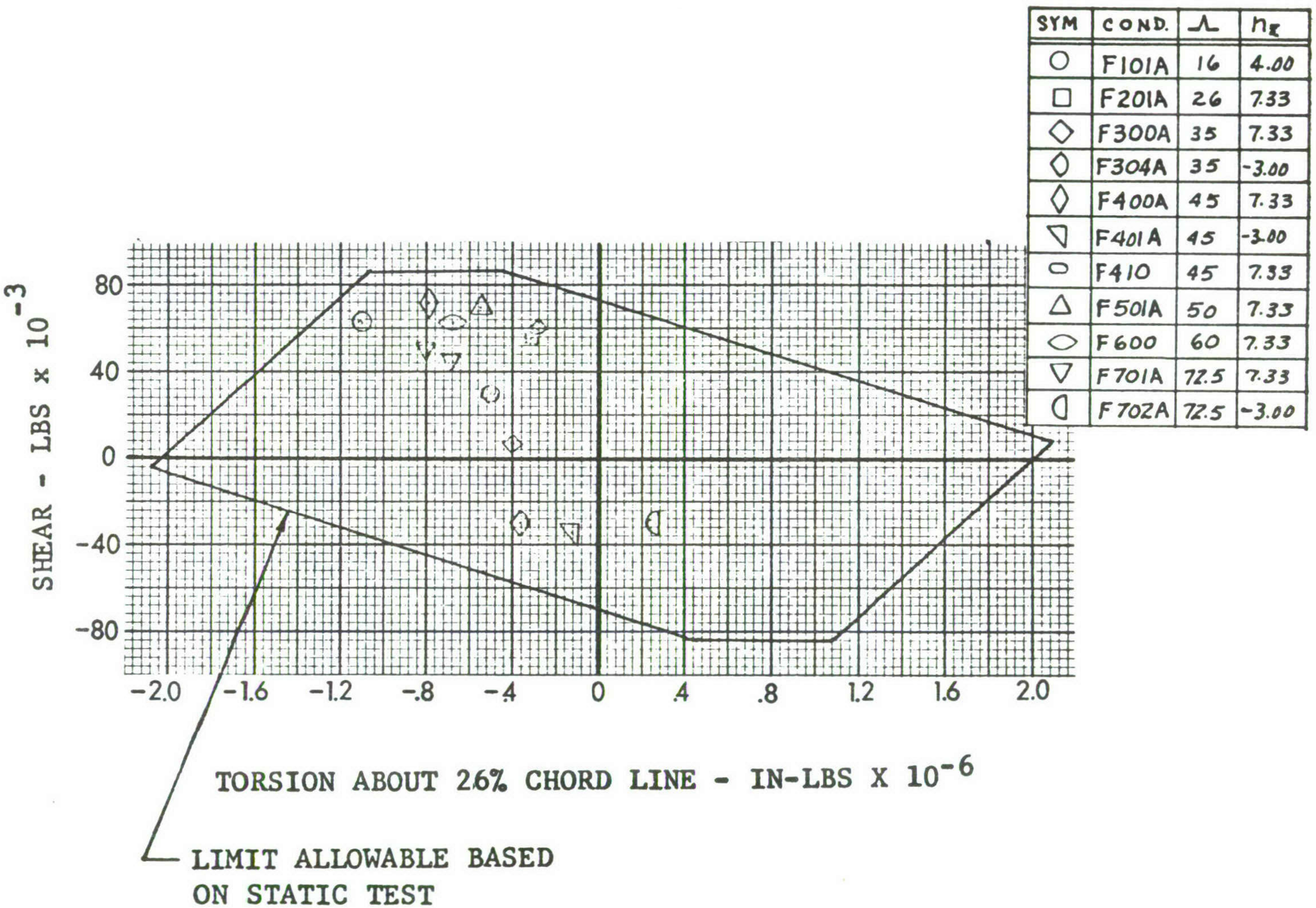


Figure 8

F-111 Wing Box Shear vs. Torsion - Station II
Summary of Balanced Symmetric Maneuver Final Loads

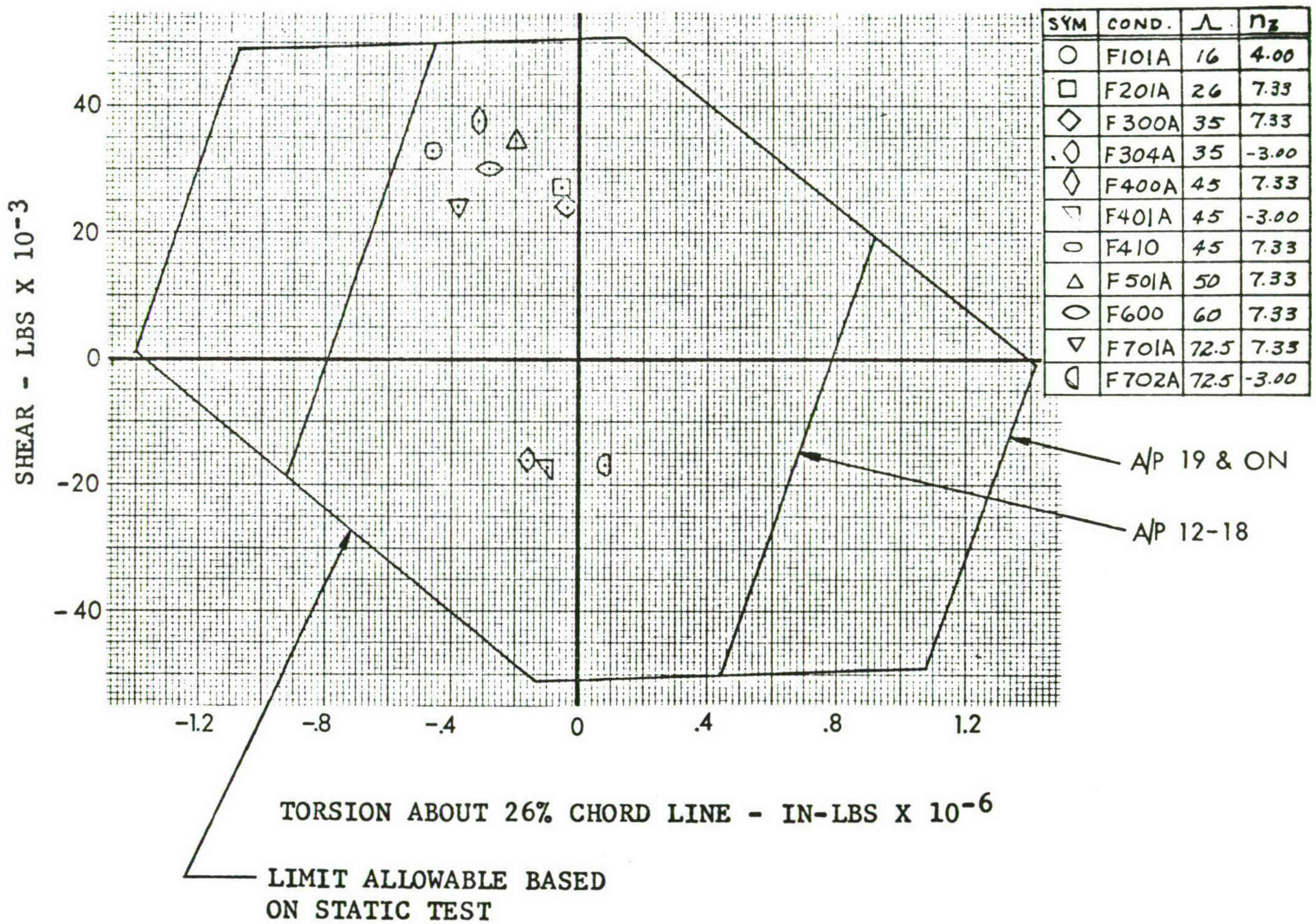
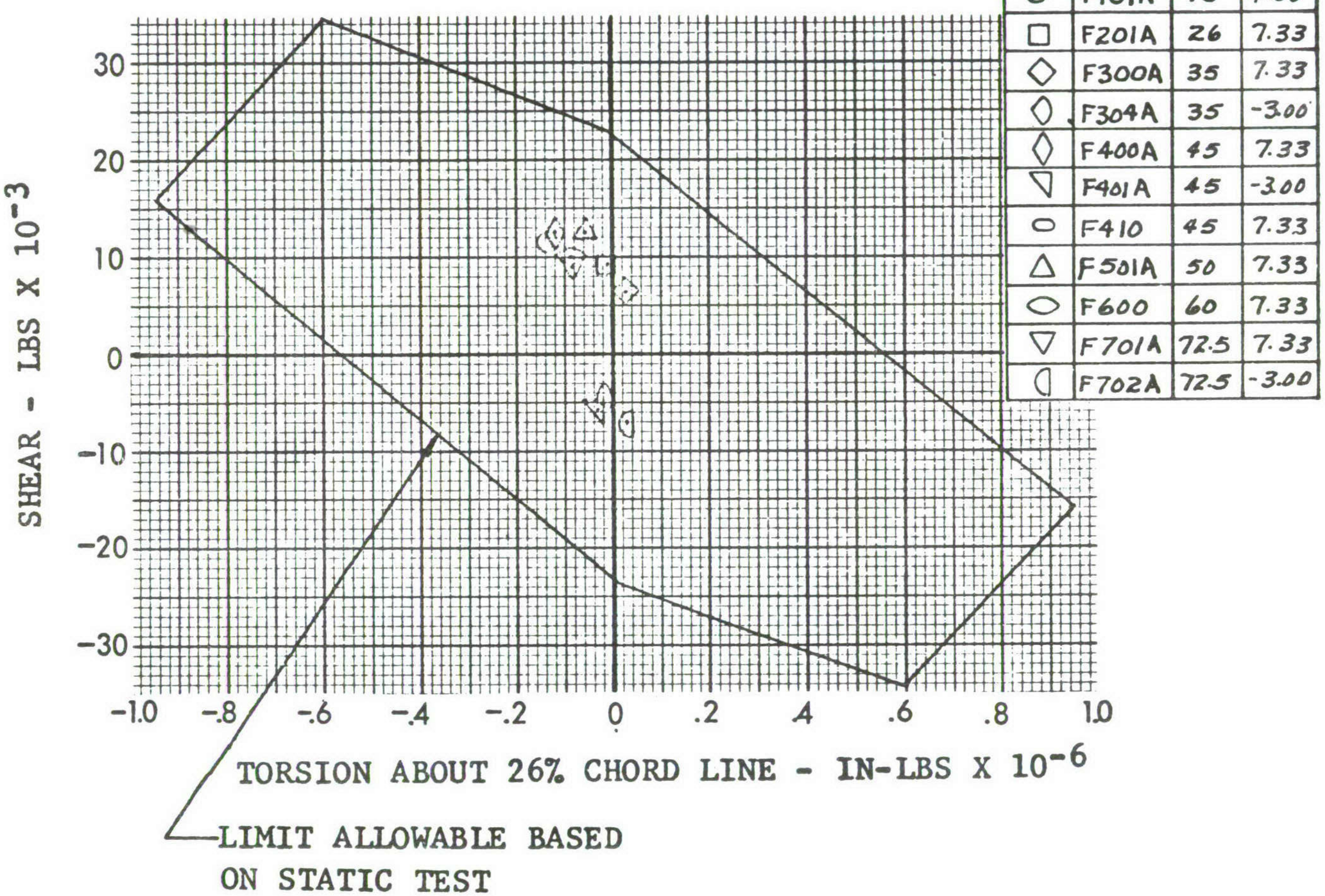


Figure 9

F-111 Wing Box Shear vs. Torsion - Station III
Summary of Balanced Symmetric Maneuver Final Loads



SYM	COND.	Λ	n_z
○	F101A	16	4.00
□	F201A	26	7.33
◇	F300A	35	7.33
◊	F304A	35	-3.00
◊	F400A	45	7.33
◸	F401A	45	-3.00
⬭	F410	45	7.33
△	F501A	50	7.33
⬭	F600	60	7.33
▽	F701A	72.5	7.33
◖	F702A	72.5	-3.00

Figure 10

F-111 Wing Box Shear vs. Torsion - Station IV
Summary of Balanced Symmetric Maneuver Final Loads

Table II

MAXIMUM FLAP TRACK LOADS AT THE REAR SPAR

CONDITION F101A

TRACK NUMBER	VERTICAL SHEAR (LBS)	BENDING MOMENT (IN-LBS)	LIMIT ALLOWABLE BENDING MOMENT (IN-LBS)	BENDING MOMENT % LIMIT
1	5,250	216,400	286,000	75.7
2	9,720	347,000	385,000	90.1
3	6,860	205,200	284,000	72.2
4	4,240	106,000	146,000	72.6
5	1,140	22,900	59,000	38.8

NOTE: Shear is at rear spar and normal to the wing plane. Bending moment is about the rear spar.

Table III

MAXIMUM SLAT TRACK BENDING MOMENTS[1]

$\Lambda = 16^\circ$, $\delta_F = 30^\circ$, A/S = 277 KCAS, h = Sea Level,

n_zW = 320,000 Lbs., $\alpha = 18.0^\circ$, $\delta_e = 18.5^\circ$

TRACK	BENDING[2] MOMENT (IN-LBS)	LIMIT ALLOWABLE BENDING MOMENT (IN-LBS)	% LIMIT ALLOWABLE
1 - Inb'd	22,360	62,200	35.9
1 - Outb'd	33,410	49,500	67.5
2 - Inb'd	30,160	39,000	77.3
2 - Outb'd	20,930	33,200	63.0
3 - Inb'd	18,460	21,900	84.3
3 - Outb'd	18,200	21,200	85.8
4 - Inb'd	13,780	17,300	79.6
4 - Outb'd	7,960	11,900	66.9

NOTES: (1) These loads do not occur at condition F101A. Slat loads at condition F101A are lower.

(2) The slat track moments and allowables are referenced to the instrumentation locations defined on page 109 of MRTP-12-529, F-111A No. 13 and No. 75 Structural Flight Test Programs Instrumentation, dated 27 May 1969.

Maximum air director door loads are developed between 30% and 40% flap extension. A secondary peak occurs at about 60% extension. These positions correspond to maximum negative door deflection and the point at which the door passes through zero deflection. Maximum load values are summarized in Table IV. None of them approach design limit.

V.1.3 Final Balanced Airplane Loads

Final clean airplane balanced symmetric maneuber loads for limit positive and negative g conditions are provided in this section. Of the eleven conditions shown in Table I, the four conditions for which various maximum wing loading occurs are singled out for presentation in this paragraph.

These loads are largely based on the demonstration maneuvers and the supporting buildups. Refinements were made to account for the difference between actual flight conditions and the criteria requirements. In many cases the minimum test altitude (5000 feet) was above the critical altitude. Normal variation in test Mach, altitude, q, airplane unbalance, etc., were accounted for in the final loads calculation. Also, an effort has been made to account for fuselage-wing interference effects in the enclosed loads. The airplane calibration carried out to about 60% of limit load, does not permit direct definition of external load where large interference loads were encountered. The loads have been modified such that they define external applied loads and do not include internal interference effects. Overwing fairing contribution to wing load has been included however, as the data available does not permit such separation. The effect is felt to be small.

Wing loads for torsion at maximum positive g, Condition F101A of Table I are presented in Table VI, Table VII and in Figures 11 through 15. Condition F101A flight parameters are summarized in Table V.

Loads for maximum positive g conditions, Condition F400A of Table I are shown in Table IX, Table X and in Figures 16 through 20. Flight parameters are summarized in Table VIII. The loads for maximum negative g conditions, Condition F401A of Table I, are shown in Table XII, Table XIII and in Figures 21 through 25. Parameters of the Condition F401A are summaried in Table XI.

Wing loads for Conditions of Torsion at maximum negative g, Condition 702A of Table I, are presented in Table XV, Table XVI and in Figures 26 through 30. These flight parameters are summarized in Table XIV.

Maximum Flap and Slat loads are shown in Table XVII, Table XVIII, Figure 13, and Figure 32.

Design conditions for wing pylons are shown in Table XIX and Figure 33.

Table IV

F-111

AIR DIRECTOR DOOR

SUMMARY OF MAXIMUM LINK LOADS

LANDING APPROACH CONFIGURATION

MAXIMUM POSITIVE LOADS

LINK	LINK LOAD (LBS)	LIMIT ALLOWABLE LINK LOAD (LBS)	% LIMIT ALLOWABLE
1	408	1,000	40.8
2	546	864	63.2
3	292	766	38.1
4	275	610	45.1

MAXIMUM NEGATIVE LOADS

LINK	LINK LOAD	LIMIT ALLOWABLE LINK LOAD (LBS)	% LIMIT ALLOWABLE
1	- 86	- 5,200	1.6
2	- 961	- 3,820	25.2
3	- 1,521	- 3,220	47.2
4	- 194	- 2,880	6.7

Table V

FLIGHT CONDITION SUMMARY

CONDITION	F101A
AIRPLANE	F-111
MANEUVER	NSPU
MACH NUMBER	330 KCAS
ALTITUDE, FT.	S.L.
GROSS WEIGHT, LBS.	77,584.7
WING SWEEP, DEG.	16
C.G., % MAC	28
n_z	+4.124
ANGLE OF ATTACK, DEG.	+9.5
ELEVATOR DEFELCTION, DEG.	-11.8
PITCH RATE, RAD/SEC.	0.611
PITCH ACCELERATION, RAD./SEC^2	0
ADIABATIC WALL TEMPERATURE, ^{o}F	84
FLAP DEFLECTION: DEG.	30
FUEL LOADING	WEIGHT, LBS.
F1	7213.9
F2	8025.0
R	2696.0
WING	0
A1	6853.0
A2	2434.3
WEAPON LOADING	WEIGHT, LBS.
BAY	2310
WING	0

Table VI

WING PIVOT NET LOADS SUMMARY

FINAL DESIGN LIMIT LOADS FOR CONDITION F101A

ITEM	LOAD	POSITIVE SIGN CONVENTION
M_{xx}	16.742×10^6 IN-LBS	TIP UP
M_{yy}	$- 6.259 \times 10^6$ IN-LBS	L.E. Up
V_p (Shear)	113.778×10^3 LBS	Up
Bending Moment (Along 26% Chord)	17.660×10^6 IN-LBS	TIP UP
Torsion (Above 26% Chord)	-2.606×10^6 IN-LBS	L.E. Up
M_{zz}	$.578 \times 10^6$ IN-LBS	TIP FORWARD

Table VII

WING NET LOADS SUMMARY

FINAL DESIGN LIMIT LOADS FOR CONDITION F101A

DISTANCE OUTB'D OF PIVOT ALONG 26% CHORD	SHEAR $X\ 10^3$ LBS	MOMENT $X\ 10^6$ IN-LBS	TORSION $X10^3$ IN-LBS	CHORD FORCE $X10^3$ LBS	SWEEPING MOMENT $X\ 10^6$ IN-LBS
0	113.778	17.660	-2.606	3.723	.578
15.75	109.289	15.903	-2.445	3.577	.520
31.50	104.643	14.219	-2.275	3.425	.465
47.25	99.799	12.609	-2.110	3.266	.413
63.00	94.720	11.077	-1.945	3.100	.363
78.75	89.365	9.627	-1.780	2.925	.315
94.50	83.664	8.264	-1.610	2.730	.270
110.25	77.568	6.995	-1.440	2.539	.229
126.00	71.111	5.824	-1.290	2.327	.191
141.75	64.378	4.757	-1.130	2.107	.156
157.50	57.408	3.798	-0.970	1.879	.124
173.25	50.281	2.950	-0.820	1.646	.097
189.00	43.076	2.215	-0.670	1.410	.072
204.75	35.870	1.593	-0.520	1.174	.052
220.50	28.822	1.084	-0.390	.943	.035
236.25	22.050	0.683	-0.290	.722	.022
252.00	15.710	0.386	-0.180	.514	.013
267.75	10.001	0.183	-0.110	.327	.006
283.50	5.158	0.064	-0.055	.169	.002
299.25	1.496	0.011	-0.020	.049	0
315.00	0	0	0	0	0

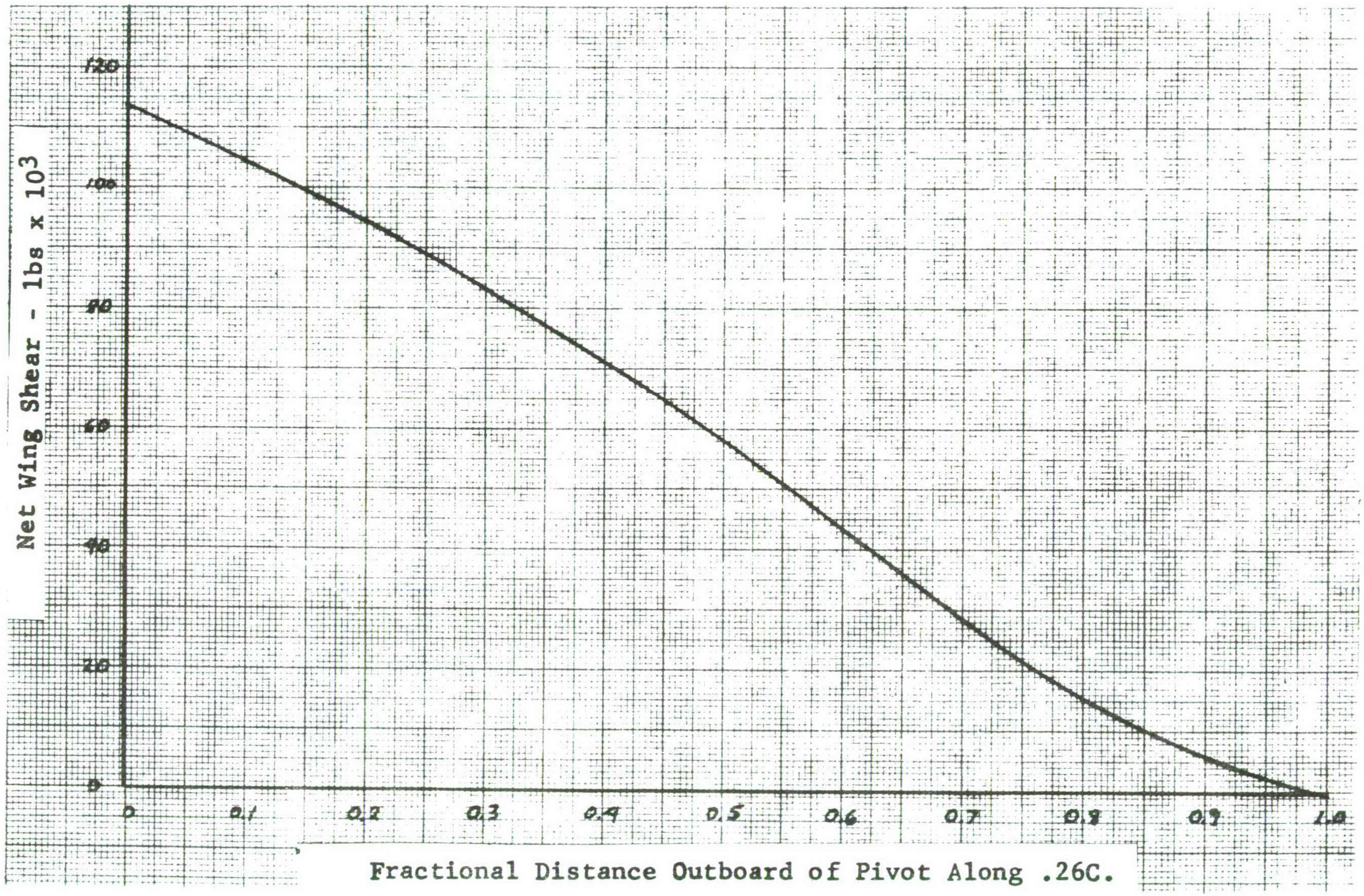


Figure 11 Final Flight Loads, Wing Spanwise Distribution of Net Shear Condition F101A $n_z W = 320{,}000$

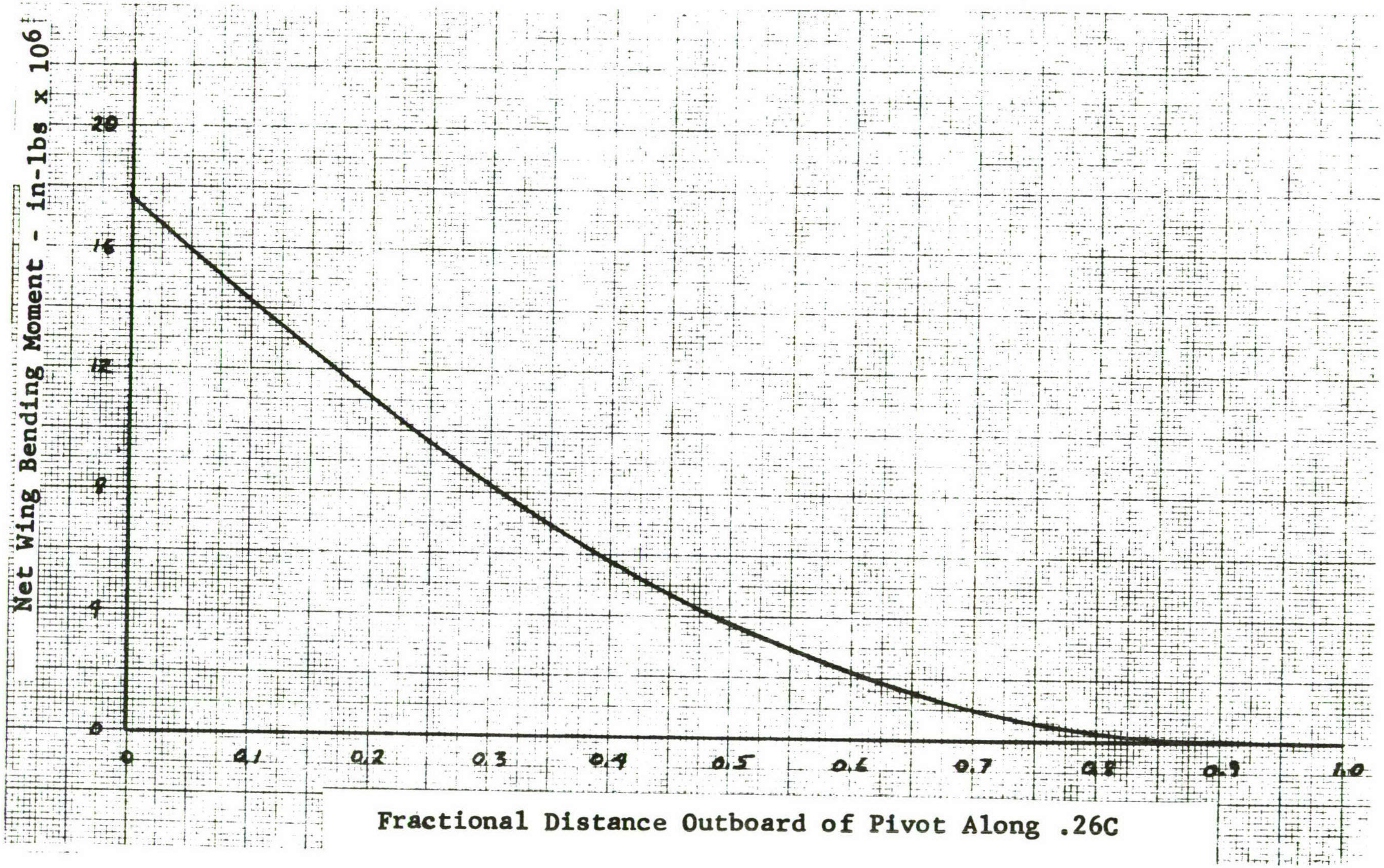


Figure 12 Final Flight Loads, Wing Spanwise Distribution of Net Bending Moment
Condition F101A $n_z W$ = 320,000

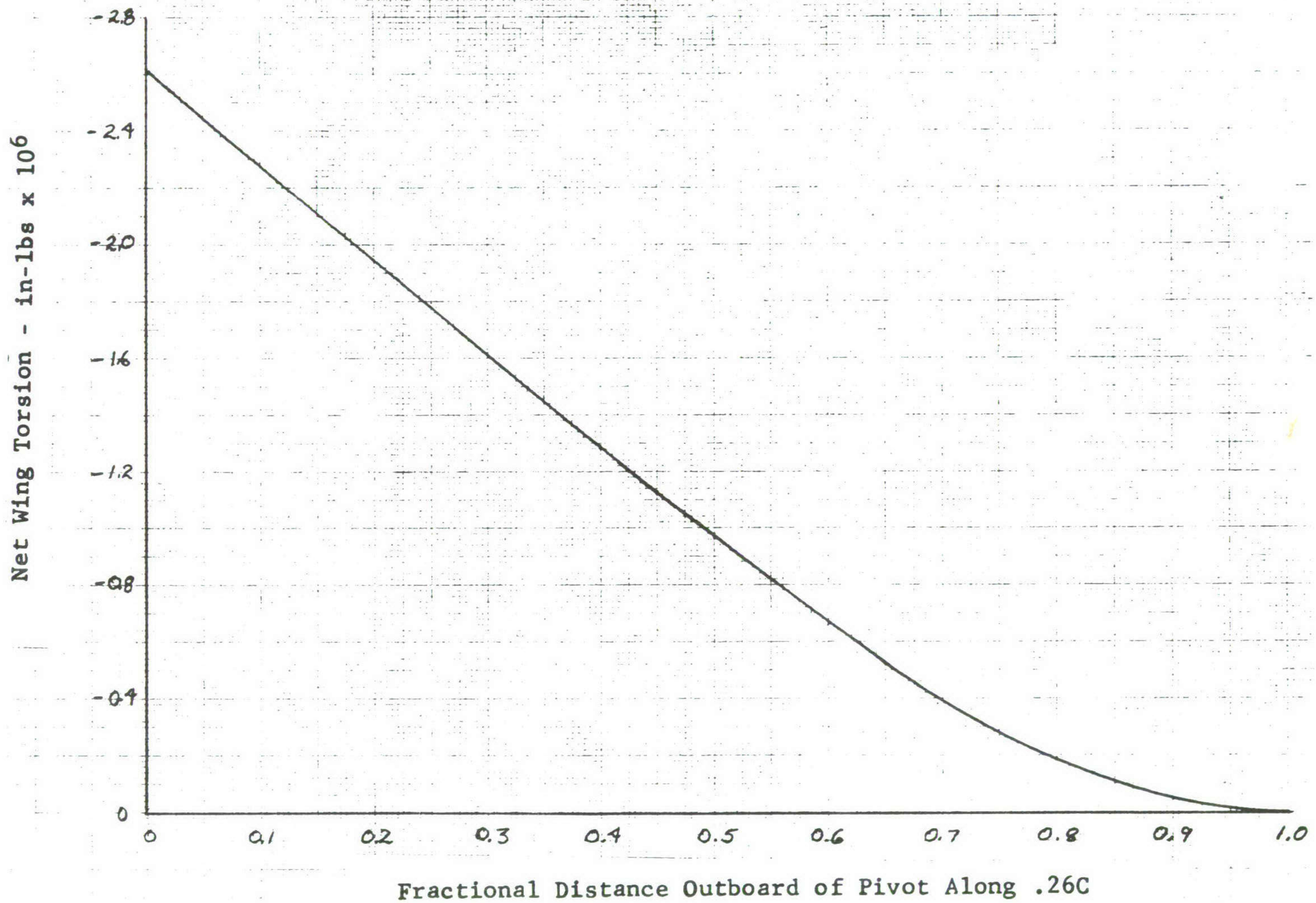


Figure 13

Final Flight Loads
Wing Spanwise Distribution of Net Torsion
Condition F101A n_zW = 320,000

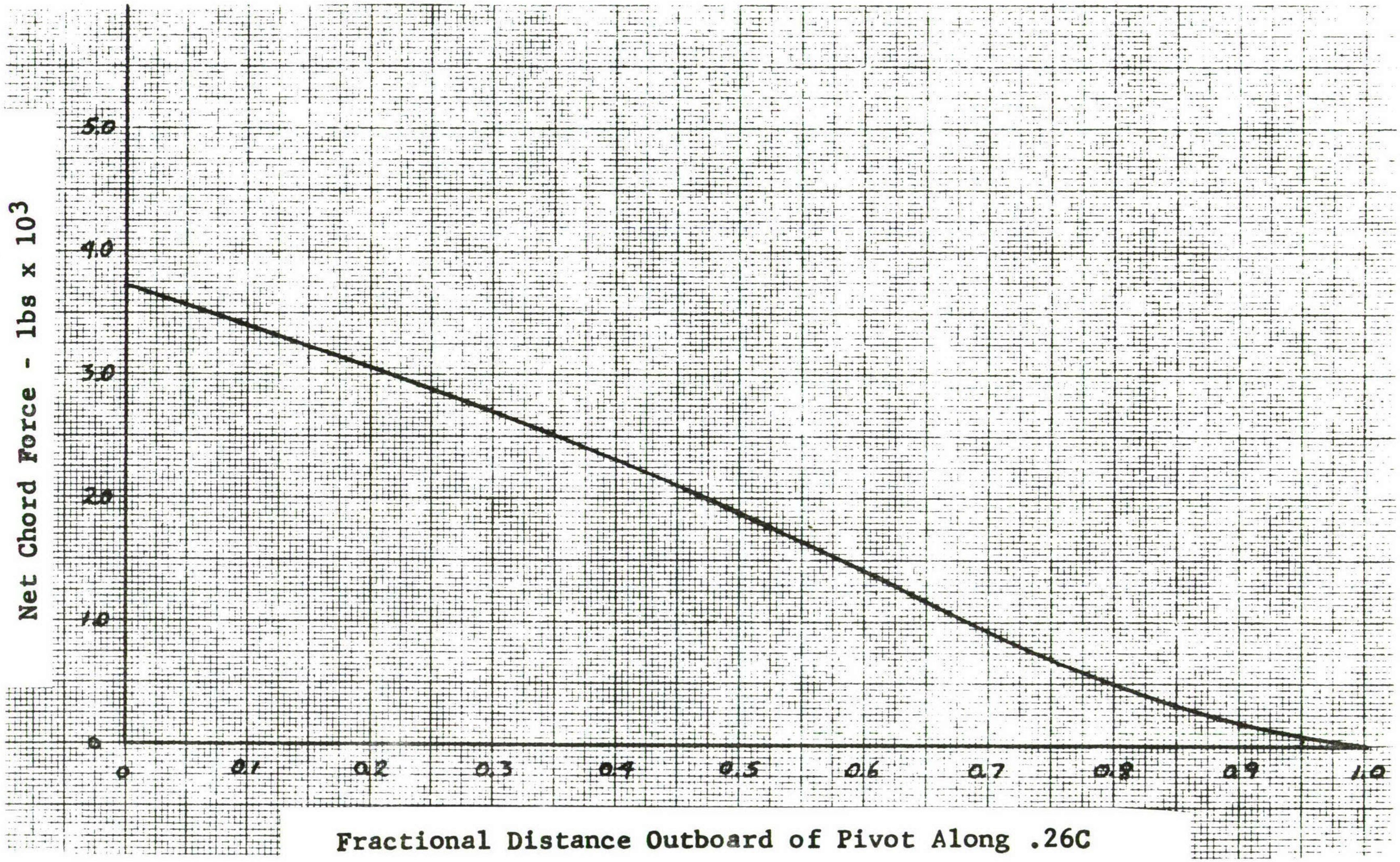


Figure 14

Final Flight Loads
Wing Spanwise Distribution of Net Chord Force
Condition F101A $n_z W = 320,000$

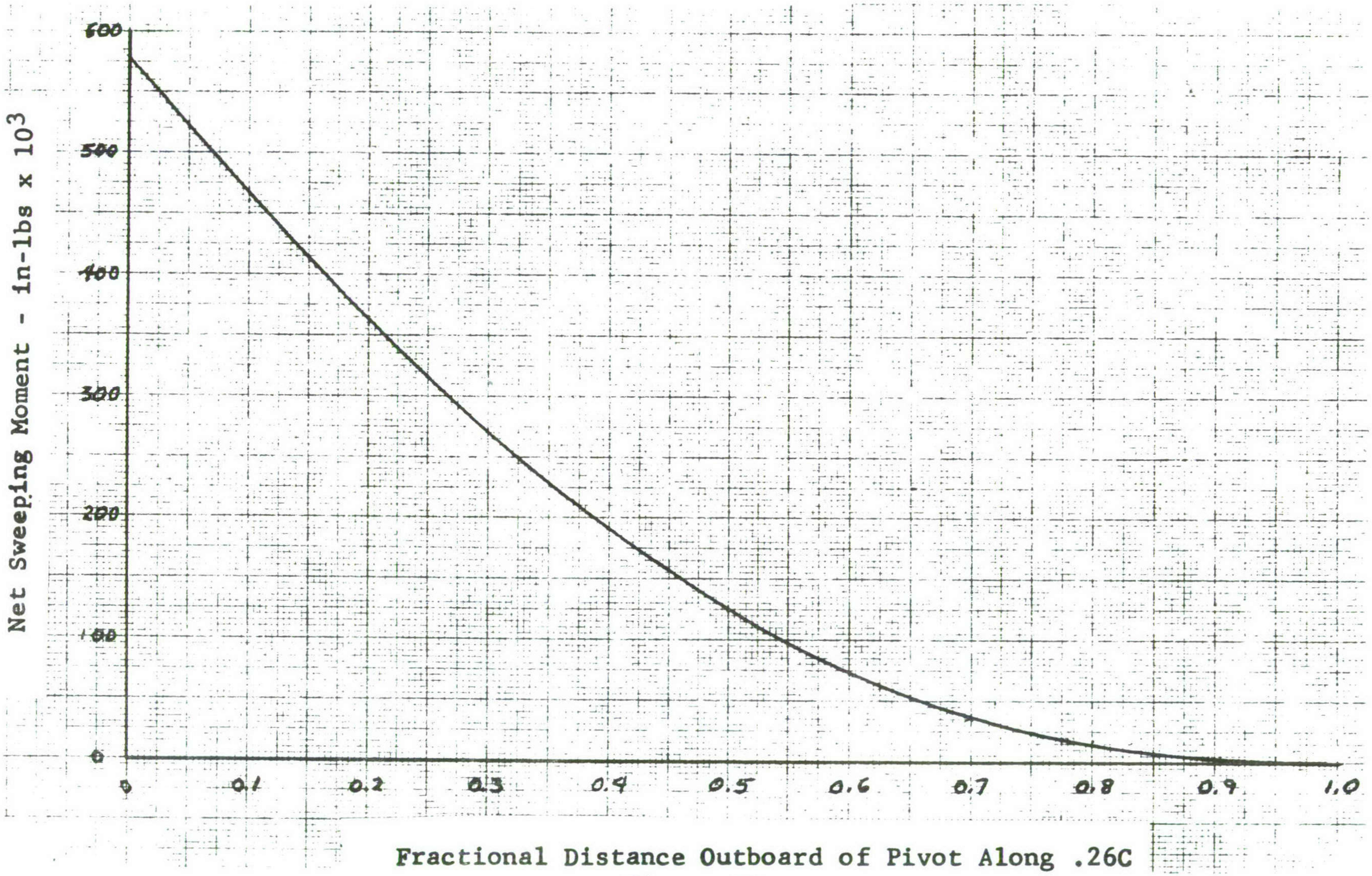


Figure 15

Final Flight Loads
Wing Spanwise Distribution of Sweeping Moment
Condition F101A n_zW = 320,000

Table VIII

FLIGHT CONDITION SUMMARY

CONDITION	F400A
AIRPLANE	F111
MANEUVER	NSPU
MACH NUMBER	1.05
ALTITUDE, FT.	2,000
GROSS WEIGHT, LBS.	72,750
WING SWEEP, DEG.	45
C. G., % MAC	32.35
n_z	7.33
ANGLE OF ATTACK, DEG.	11.3
ELEVATOR DEFLECTION, DEG.	- 17.6
PITCH RATE, RAD/SEC.	0.28
PITCH ACCELERATION, RAD./SEC^2	0
ADIABATIC WALL TEMPERATURE, $^{\circ}$F	155

FUEL LOADING	WEIGHT, LBS
F1	4664.8
F2	8025.0
R	2696.0
WING	0
A1	6853.0
A2	148.7

WEAPON LOADING	WEIGHT, LBS.
BAY	2310
WING	0

Table IX

WING PIVOT NET LOADS SUMMARY

FINAL DESIGN LIMIT LOADS FOR CONDITION F400A

ITEM	LOAD	POSITIVE SIGN CONVENTION
M_{xx}	14.127×10^6 IN-LBS	TIP UP
M_{yy}	-13.473×10^6 IN-LBS	L.E. Up
V_p (Shear)	127.60×10^3 Lbs	Up
Bending Moment (Along 26% Chord)	19.517×10^6 IN-LBS	TIP UP
Torsion (Above 26% Chord)	$-.836 \times 10^6$ IN-LBS	L.E. Up
M_{zz}	$.1730 \times 10^6$ IN-LBS	TIP FORWARD

Table X

WING NET LOADS SUMMARY

FINAL DESIGN LIMIT LOADS FOR CONDITION F400A

DISTANCE OUTB'D OF RIVET ALONG 26% CHORD	SHEAR $X10^3$ LBS	MOMENT $X\ 10^6$ IN-LBS	TORSION $X\ 10^6$ IN-LBS	CHORD FORCE $X\ 10^3$ LBS	SWEEPING MOMENT $X\ 10^6$ IN LBS
0	127.6	19.517	-0.837	1.129	.1730
15.75	122.3	17.549	-1.09	1.085	:1554
31.50	116.6	15.668	-1.23	1.035	.1385
47.25	110.7	13.878	-1.28	0.984	.1224
63.00	104.4	12.184	-1.30	0.931	.1072
78.75	98.1	10.590	-1.28	0.877	.0928
94.50	91.7	9.095	-1.20	0.821	.0793
110.25	85.2	7.702	-1.08	0.763	.0667
126.00	78.5	6.413	- .93	0.706	.0550
141.75	71.3	5.233	- .80	0.646	.0442
157.50	63.5	4.171	- .67	0.565	.0346
173.25	55.2	3.237	- .55	0.475	.0263
189.00	47.0	2.432	- .45	0.374	.0195
204.75	38.9	1.755	- .35	0.287	.0143
220.50	31.2	1.203	- .27	0.229	.0102
236.25	24.0	.769	- .21	0.183	.0069
252.00	17.4	.443	- .15	0.140	.0043
267.75	11.4	.216	- .10	0.102	.0024
283.50	6.1	.078	- .06	0.066	.0011
299.25	1.9	.015	- .01	0.034	.0003
315.00	0	0	0	0	0

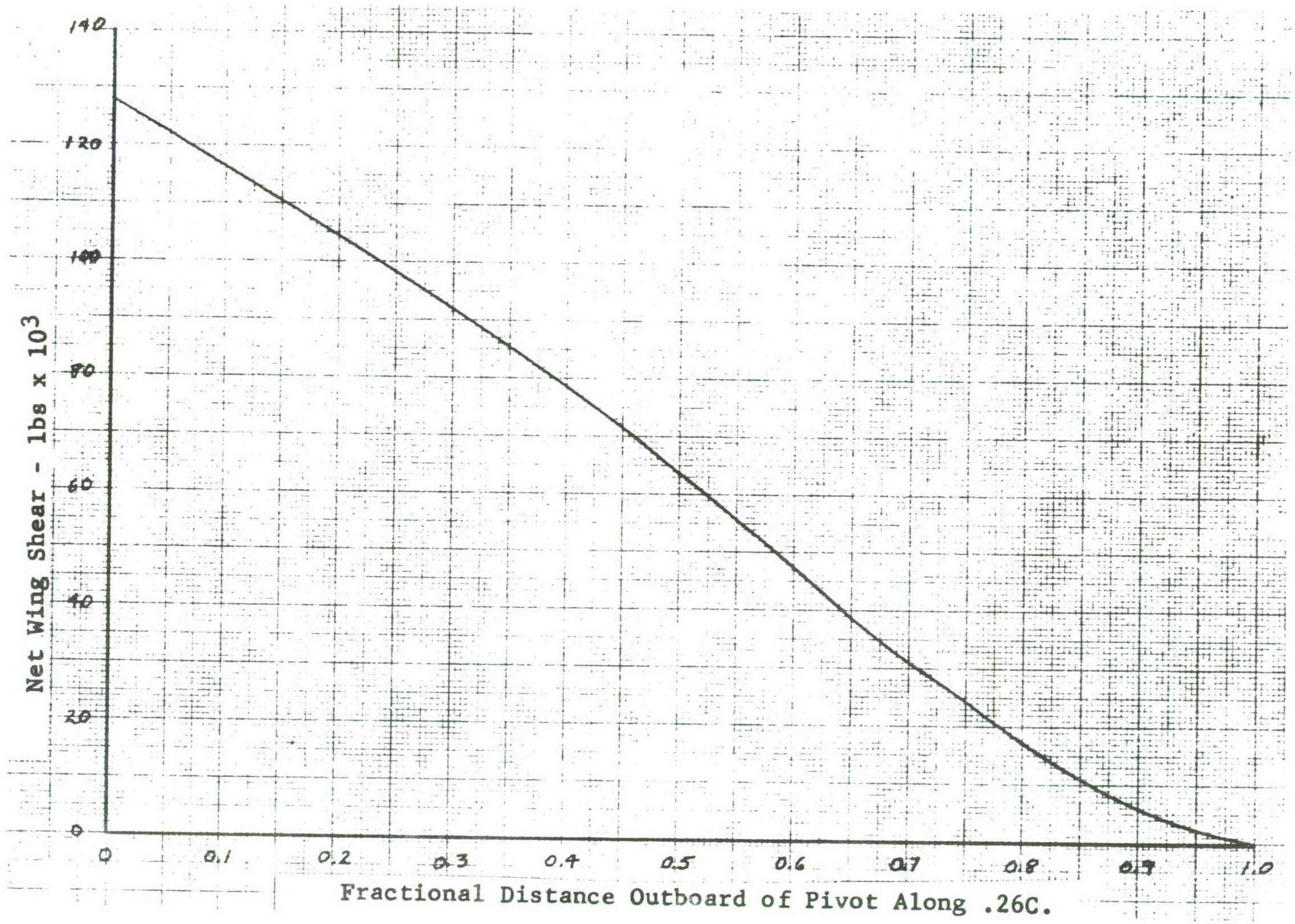


Figure 16

Final Flight Loads
Wing Spanwise Distribution of Net Shear
Condition F400A $n_z W$ = 533,000

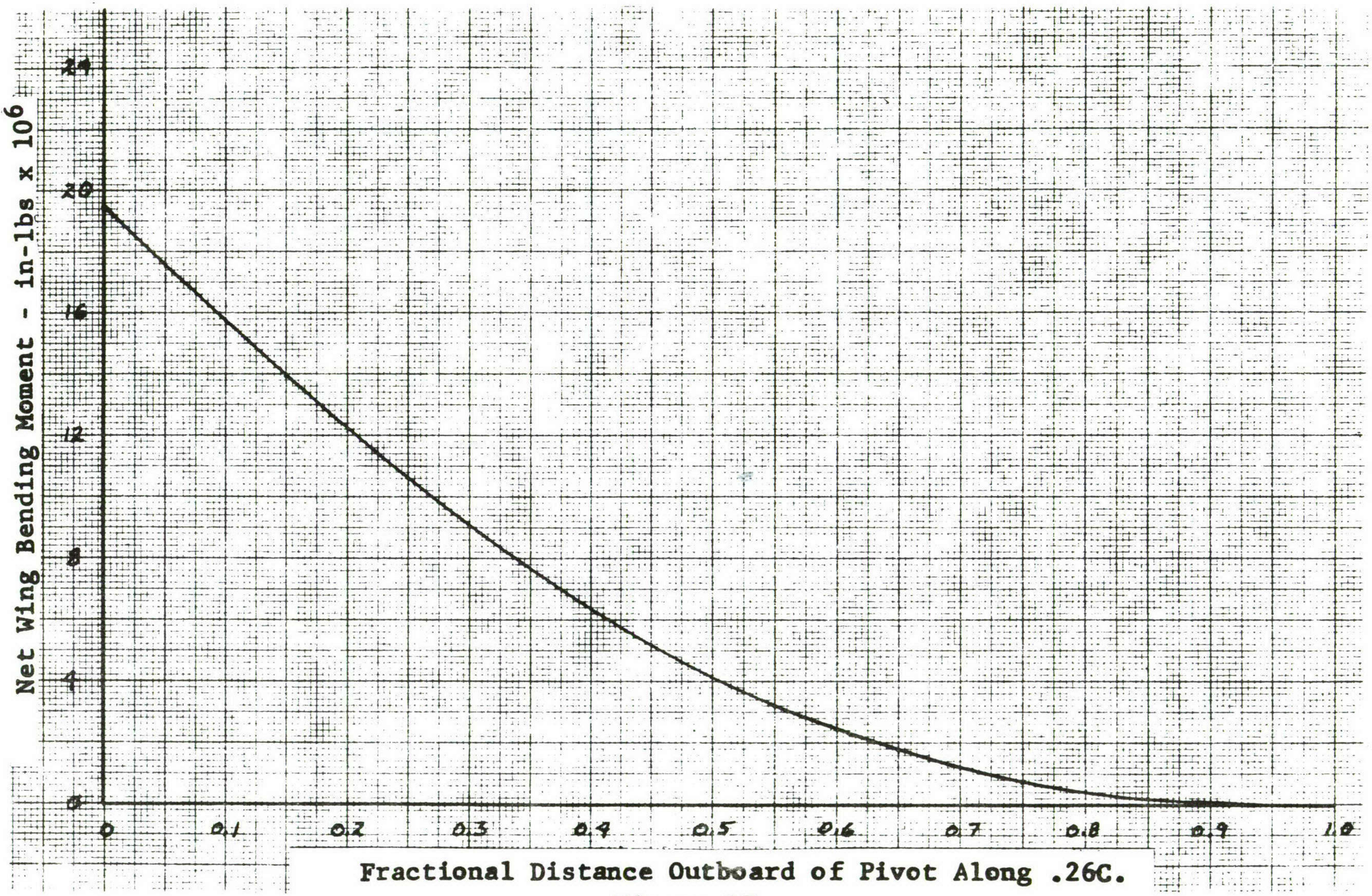


Figure 17
Final Flight Loads
Wing Spanwise Distribution of Net Bending Moment
Condition F400A $n_z W$ = 533,000

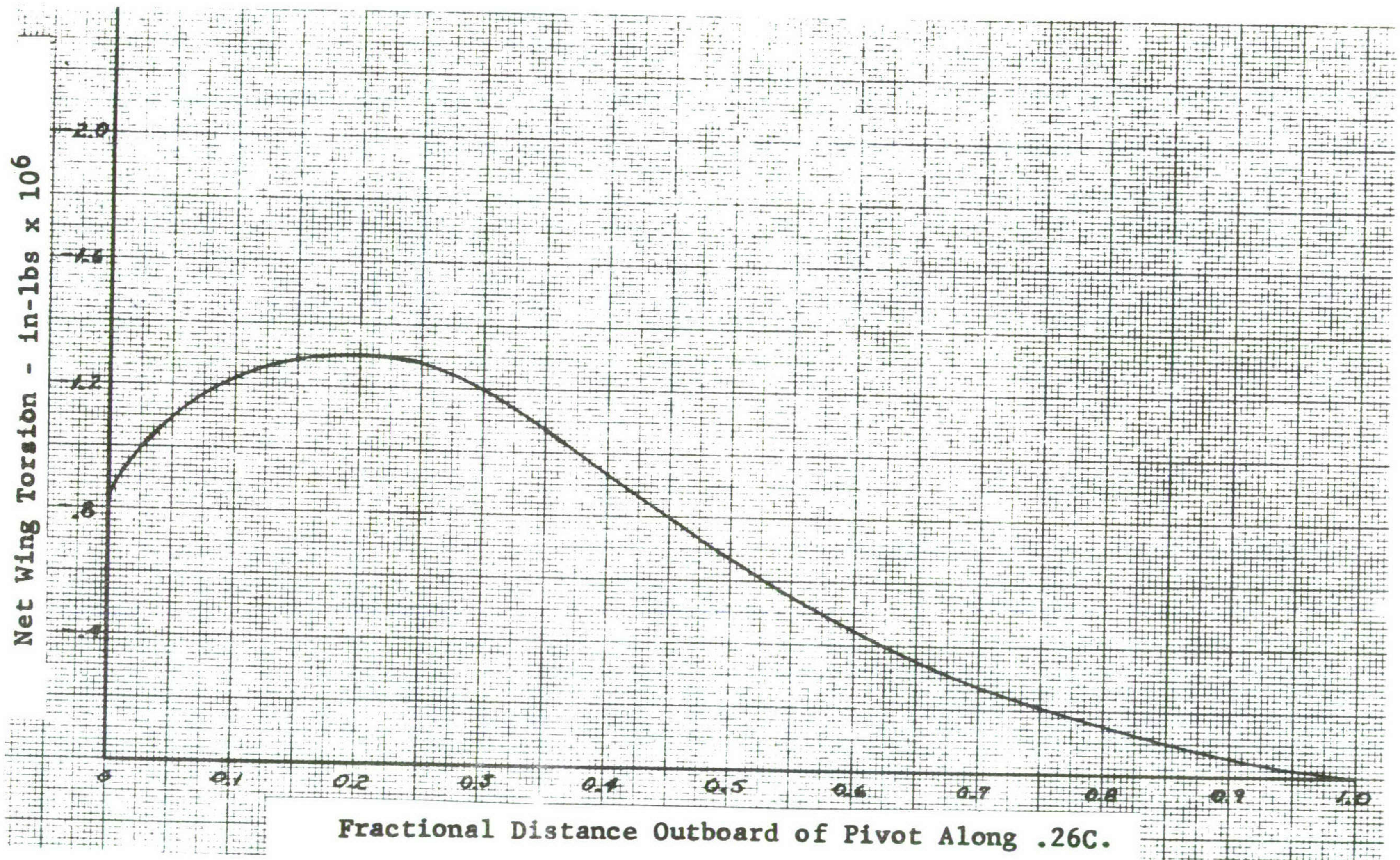


Figure 18

Final Flight Loads

Wing Spanwise Distribution of Net Torsion

Condition F400A $n_z W$ = 533,000

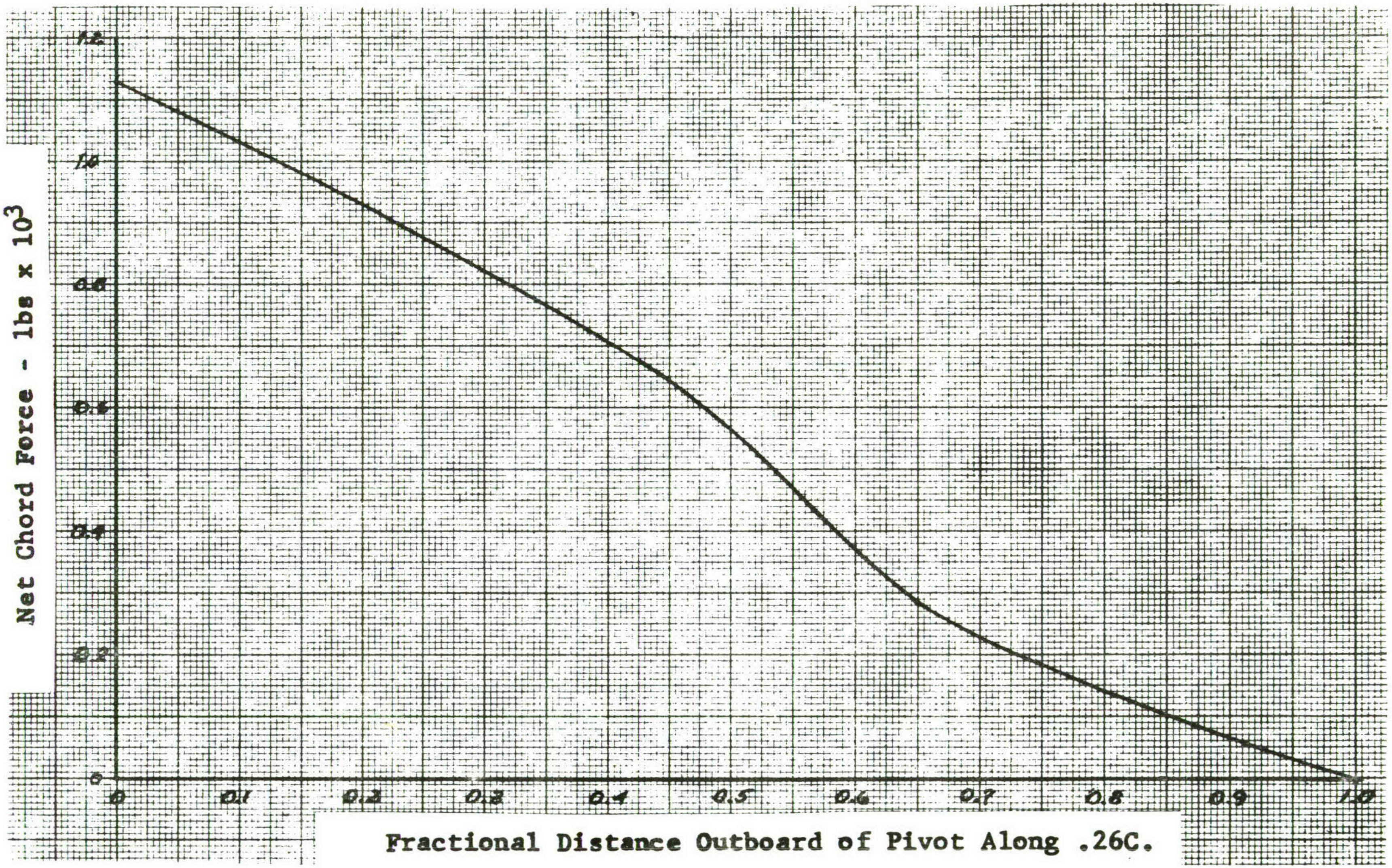


Figure 19

Final Flight Loads

Wing Spanwise Distribution of Net Chord Force

Condition F400A $n_z W$ = 533,000

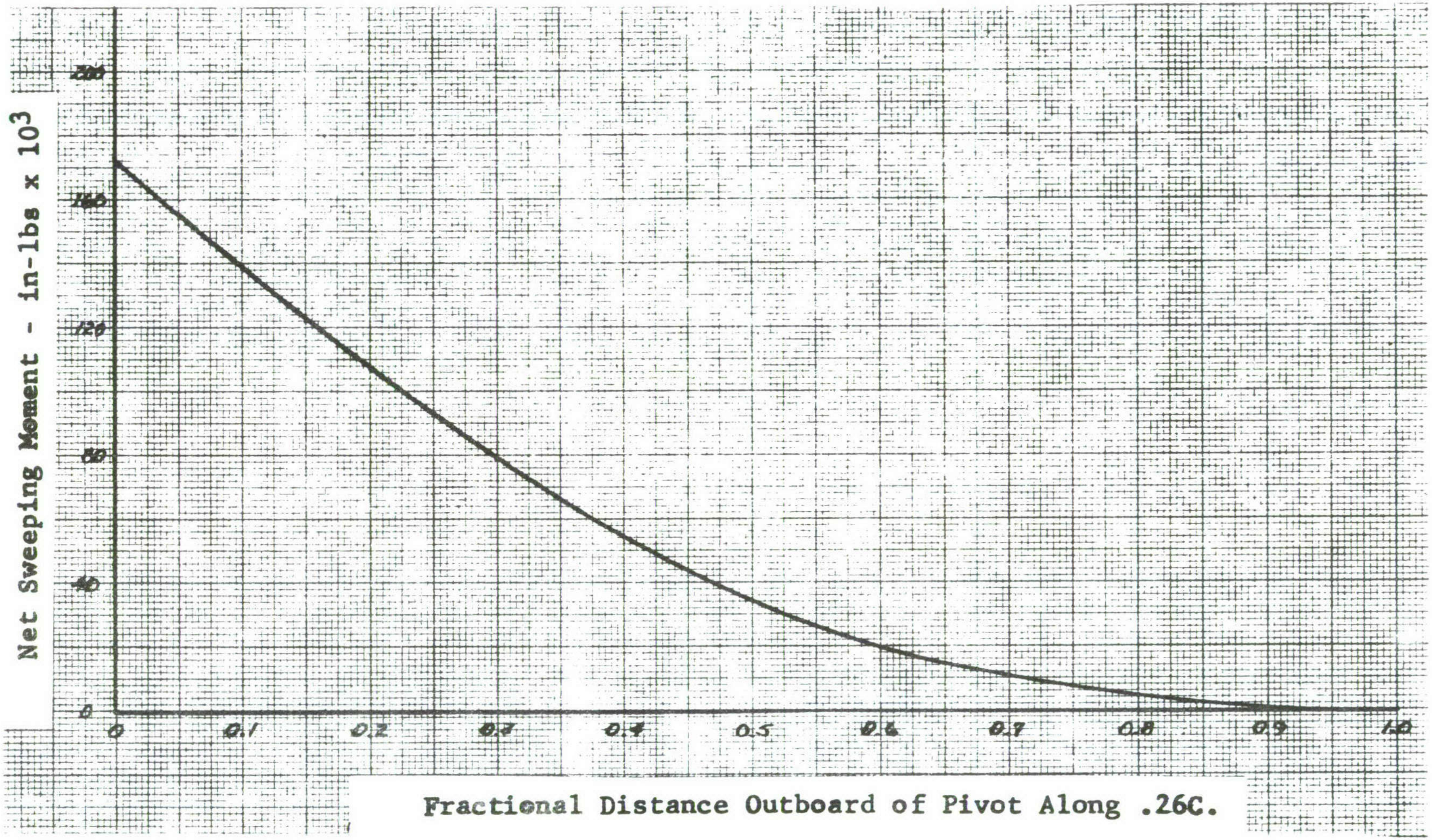


Figure 20

Final Flight Loads
Wing Spanwise Distribution of Sweeping Moment
Condition F400A n_zW = 533,000

Table XI

FLIGHT CONDITION SUMMARY

CONDITION	F401A
AIRPLANE	F111
MANEUVER	NSPO
MACH NUMBER	1.05
ALTITUDE, FT.	8,000
GROSS WEIGHT, LBS.	72,750
WING SWEEP, DEG.	45
C.G., % MAC	32.0
n_z	- 3.00
ANGLE OF ATTACK, DEG.	- 5.10
ELEVATOR DEFLECTION, DEG.	15.00
PITCH RAGE, RAD/SEC.	- 0.157
PITCH ACCELERATION, RAD./SEC^2	0
ADIABATIC WALL TEMPERATURE, ^oF	126
FUEL LOADING	WEIGHT, LBS.
F1	4664.8
F2	8025.0
R	2696.0
WING	0
A1	6853.0
A2	148.7
WEAPON LOADING	WEIGHT, LBS.
BAY	2310.0
WING	0

Table XII

WING PIVOT NET LOADS SUMMARY

FINAL DESIGN LIMIT LOADS FOR CONDITION F401A

ITEM	LOAD	POSITIVE SIGN CONVENTION
M_{xx}	-7.377×10^6 In-Lbs	Tip Up
M_{yy}	$+6.614 \times 10^6$ In-Lbs	L.E. Up
V_p (Shear)	-62.890×10^3 Lbs	Up
Bending Moment (Along 26% Chord)	-9.914×10^6 In-Lbs	Tip Up
Torsion (About 26% Chord)	$+ 0.119 \times 10^6$ In-Lbs	L.E. Up
M_{zz}	-1.282×10^6 In-Lbs	Tip Forward

Table XIII

WING NET LOADS SUMMARY

FINAL DESIGN LIMIT LOADS FOR CONDITION F401A

DISTANCE OUTB'D OF PIVOT ALONG 25% CHORD	SHEAR X 10^3 LBS	MOMENT X 10^6 IN-LBS	TORSION X 10^6 IN-LBS	CHORD FORCE X 10^3 LBS	SWEEPING MOMENT X 10^6 IN-LBS
0	-62.890	-9.914	0.119	-8.132	-1.282
15.75	-62.417	-8.927	0.112	-8.071	-1.154
31.50	-61.039	-7.954	0.100	-7.893	-1.028
47.25	-58.849	-7.010	0.081	-7.610	-0.906
63.00	-55.912	-6.107	0.053	-7.230	-0.790
78.75	-52.298	-5.254	0.017	-6.763	-0.679
94.50	-48.250	-4.463	-0.029	-6.274	-0.577
110.25	-44.029	-3.736	-0.072	-5.694	-0.483
126.00	-39.745	-3.076	-0.108	-5.140	-0.398
141.75	-35.445	-2.484	-0.127	-4.584	-0.321
157.50	-31.161	-1.960	-0.129	-4.030	-0.253
173.25	-26.917	-1.502	-0.127	-3.481	-0.194
189.00	-22.727	-1.111	-0.119	-2.939	-0.144
204.75	-18.616	-0.786	-0.108	-2.407	-0.102
220.50	-14.648	-0.524	-0.091	-1.894	-0.068
236.25	-10.915	-0.322	-0.069	-1.411	-0.042
252.00	- 7.528	-0.177	-0.048	-0.973	-0.023
267.75	- 4.615	-0.082	-0.031	-0.597	-0.011
283.50	- 2.260	-0.027	-0.018	-0.292	-0.003
299.25	- 0.614	-0.005	-0.007	-0.079	-0.001
315.00	0	0	0	0	0

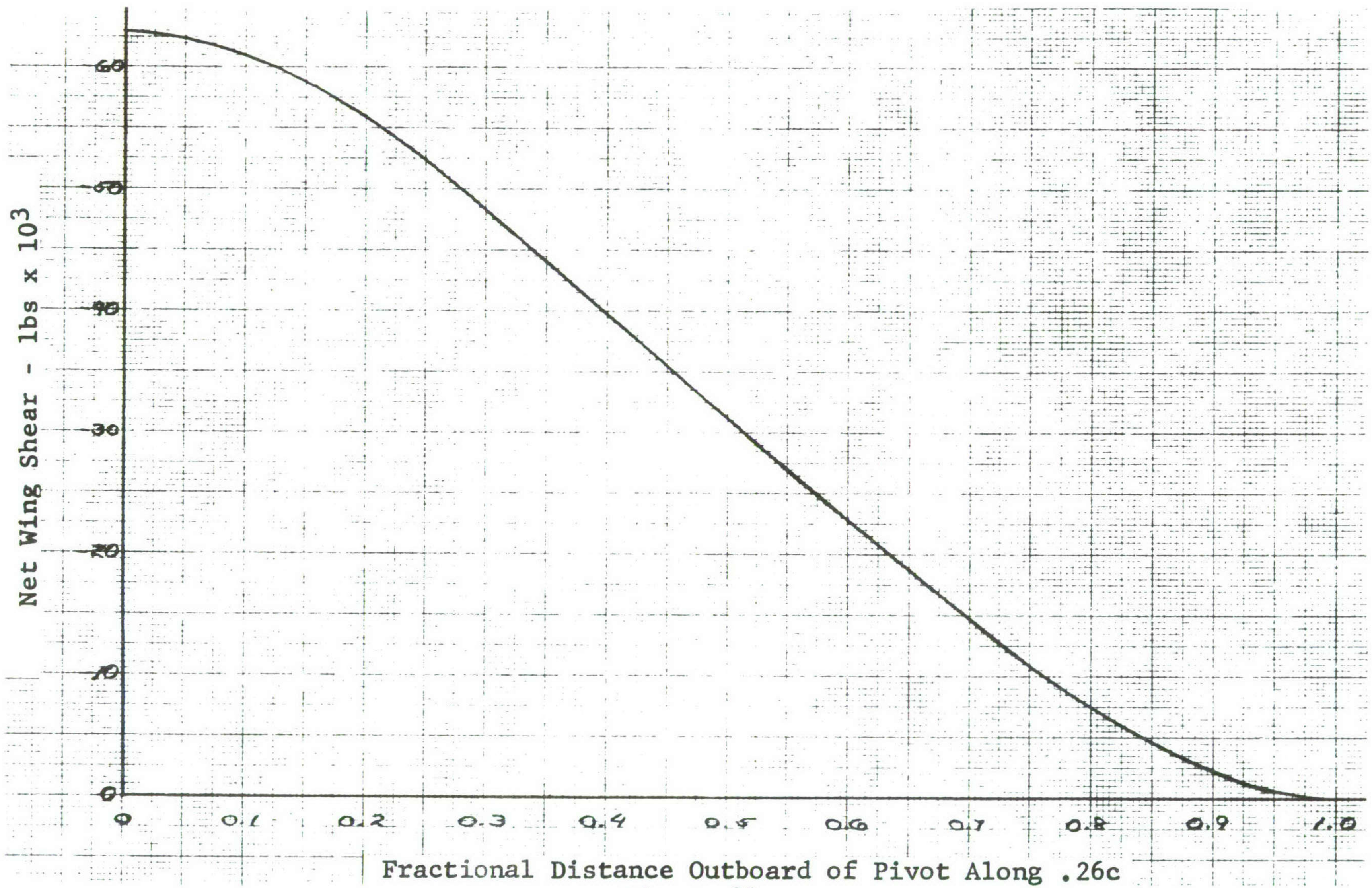


Figure 21

Final Flight Loads
Wing Spanwise Distribution of Net Shear
Condition F401A n_zW = 218,000

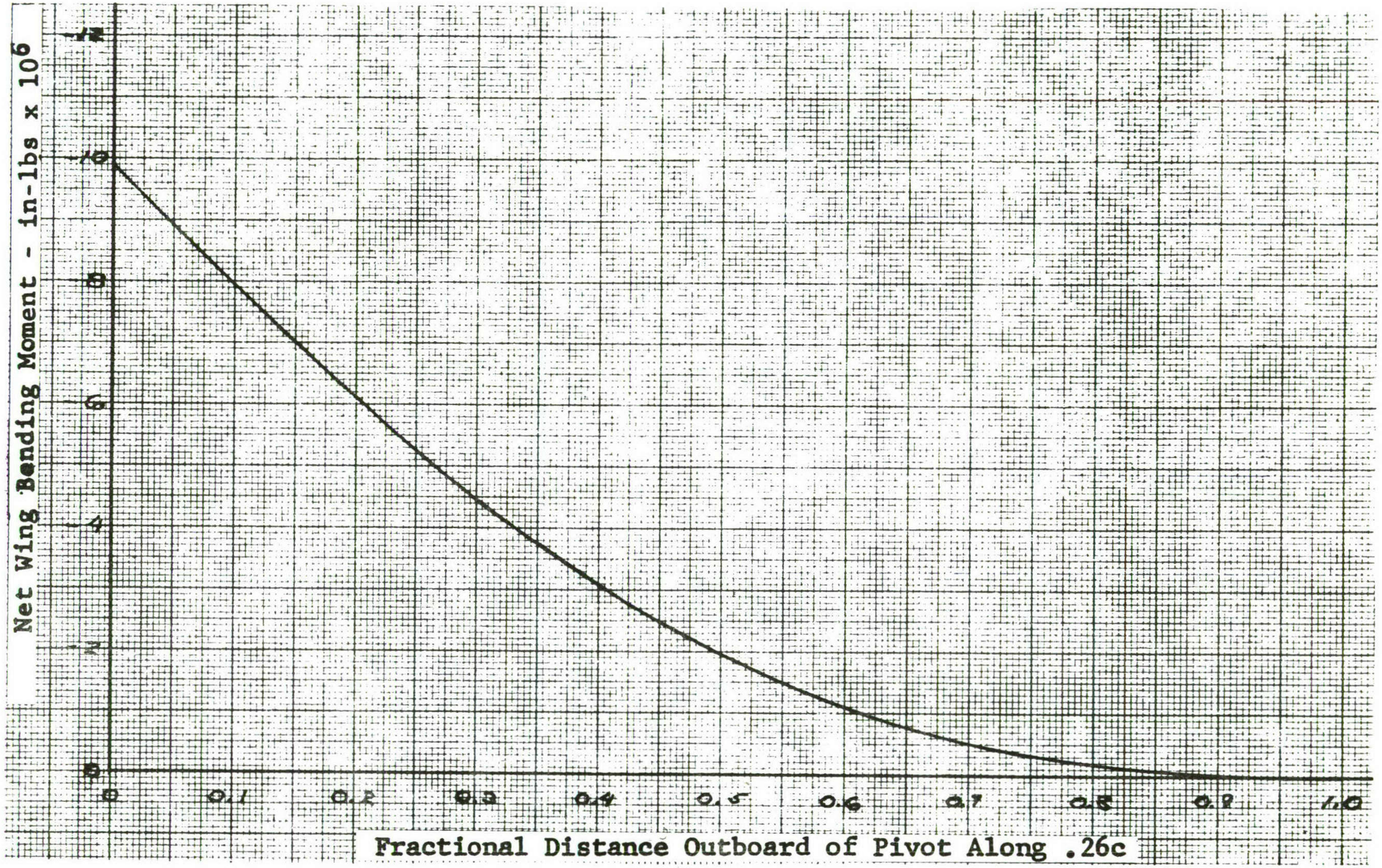


Figure 22
Final Flight Loads
Wing Spanwise Distribution of Net Bending Moment
Condition F401A n_zW = -218,000

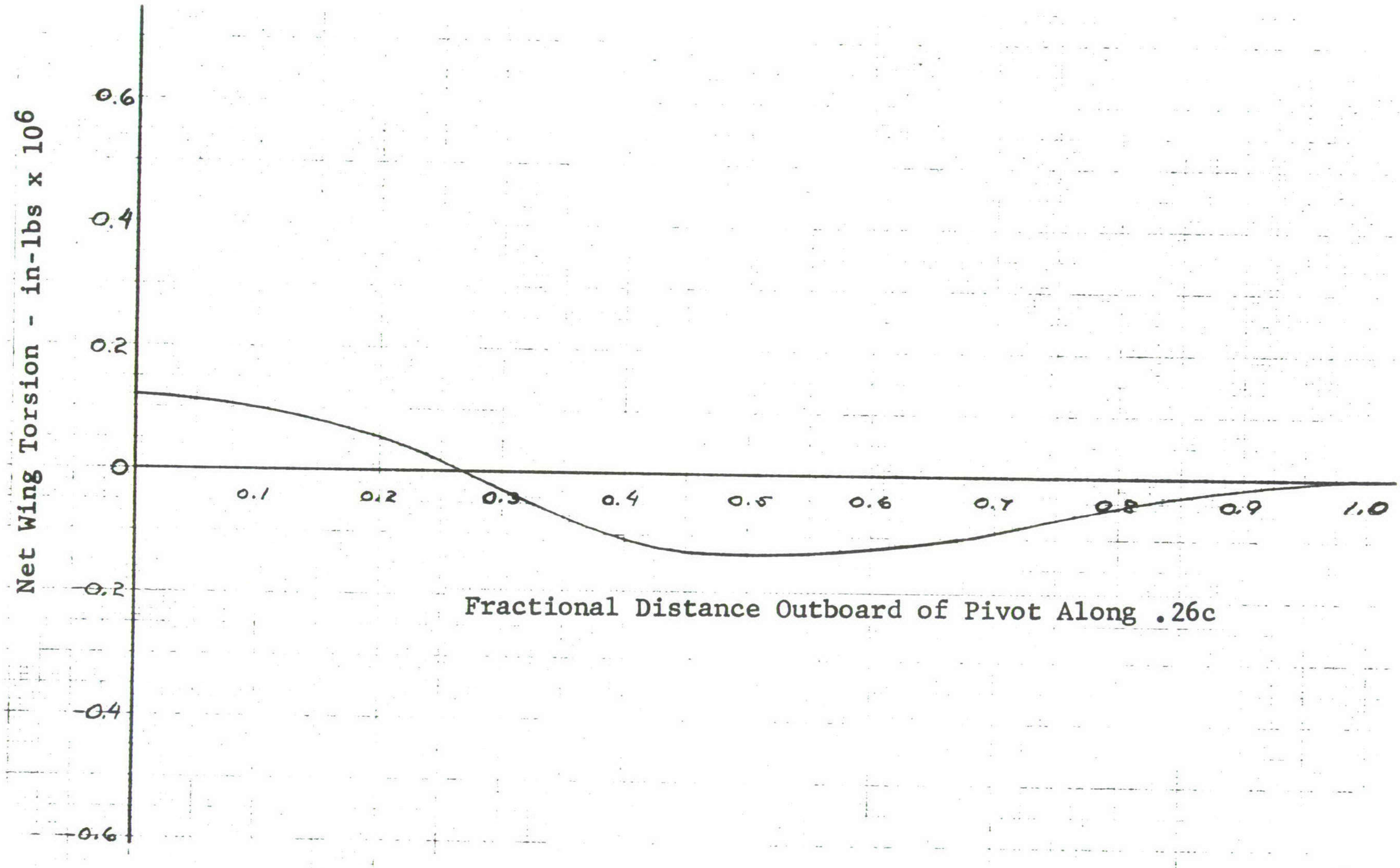


Figure 23

Final Flight Loads
Wing Spanwise Distribution of Net Torsion
Condition F401A n_zW = -218,000

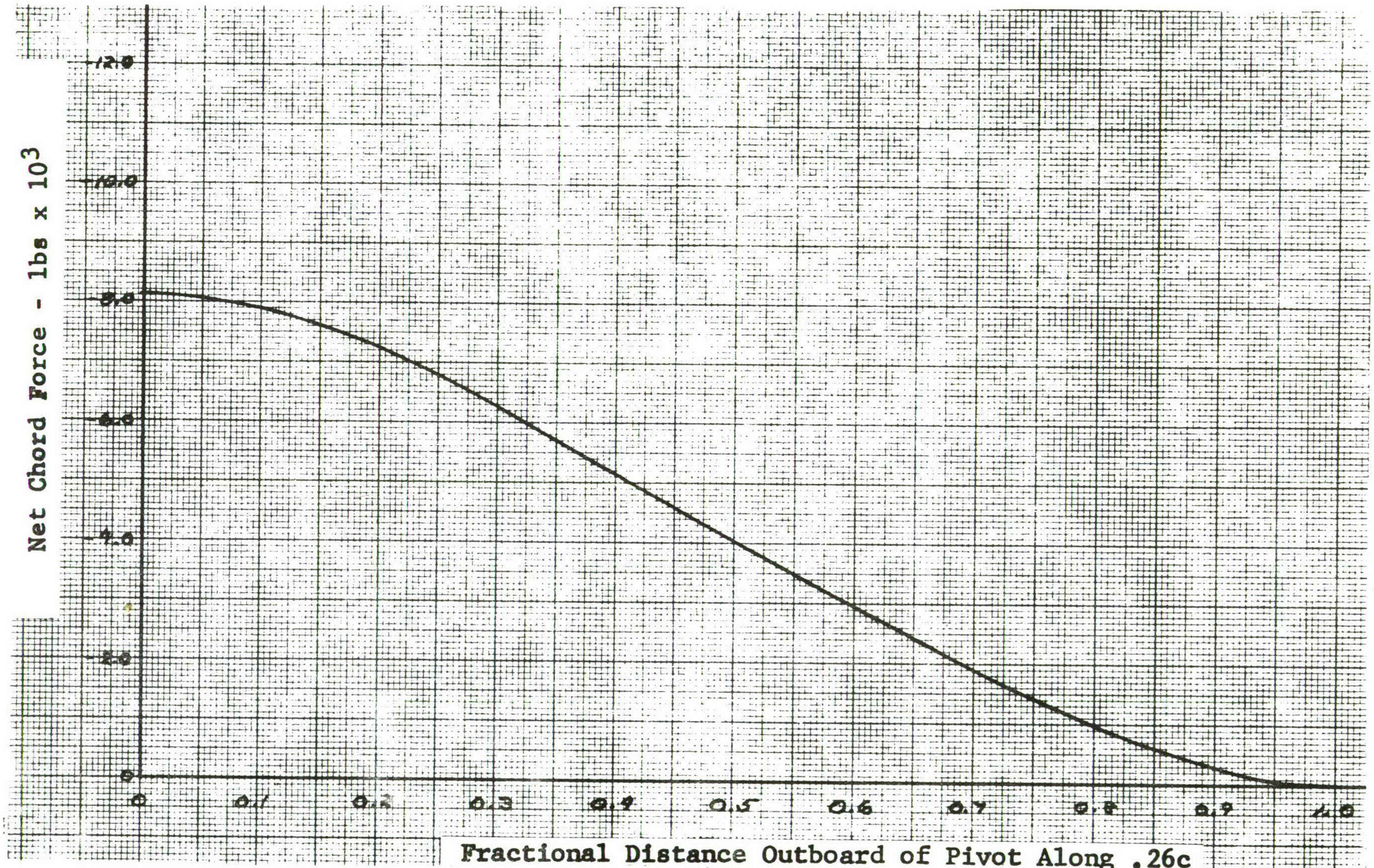


Figure 24

Final Flight Loads
Wing Spanwise Distribution of Net Chord Force
Condition F401A n_zW = -218,000

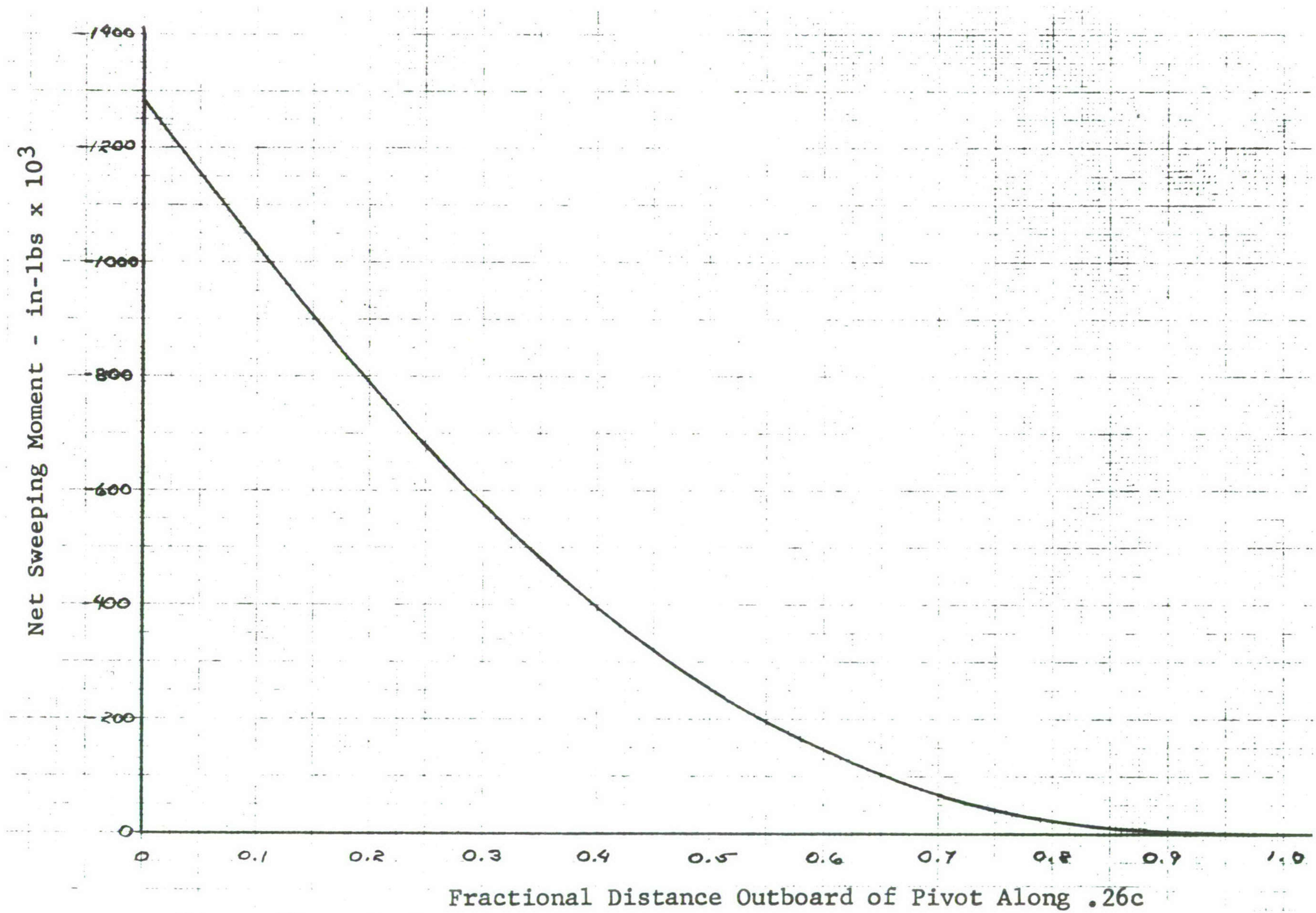


Figure 25 Final Flight Loads, Wing Spanwise Distribution of Sweeping Moment Condition F401A $n_z W$ = -218,000

Table XIV

FLIGHT CONDITION SUMMARY

CONDITION	F-702A
AIRPLANE	F-111
MANEUVER	NSPO
MACH NUMBER	1.40
ALTITUDE, FT.	17,500
GROSS WEIGHT, LBS.	72,750
WING SWEEP, DEG.	72.5
C.G., % MAC	34.0
n_z	-3.00
ANGLE OF ATTACK, DEG.	-6.4
ELEVATOR DEFLECTION, DEG.	14.4
PITCH RATE, RAD/SEC.	-0.105
PITCH ACCELERATION, RAD/SEC^2	0
ADIABATIC WALL TEMPERATURE, ^{o}F	159
FUEL LOADING	WEIGHT, LBS.
F1	4664.8
F2	8025.0
R	2696.0
WING	0.0
A1	6853.0
A2	148.7
WEAPON LOADING	WEIGHT, LBS.
BAY	2310.0
WING	0.0

Table XV

WING PIVOT NET LOADS SUMMARY

FINAL DESIGN LIMIT LOADS FOR CONDITION F702

ITEM	LOAD	POSITIVE SIGN CONVENTION
M_{xx}	-2.903×10^6 In - Lbs	Tip Up
M_{yy}	7.784×10^6 In - Lbs	L.E. Up
V_p (Shear)	-46.690×10^3 Lbs	Up
Bending Moment (Along 26% Chord)	-8.301×10^6 In-Lbs	Tip Up
Torsion (About 26% Chord)	0.123×10^6 In-Lbs	L.E. Up
M_{zz}	0.5308×10^6 In-Lbs	Tip Forward

Table XVI

WING NET LOADS SUMMARY

FINAL DESIGN LIMIT LOADS FOR CONDITION F702

DISTANCE OUTB'D OF PIVOT ALONG 26% CHORD	SHEAR $\times 10^3$ LBS	MOMENT $\times 10^6$ IN-LBS	TORSION $\times 10^6$ IN-LBS	CHORD FORCE $\times 10^3$ LBS	SWEEPING MOMENT $\times 10^6$ IN-LBS
0	-46.690	-8.301	0.123	2.986	0.531
15.75	-46.722	-7.565	0.180	2.988	0.484
31.50	-46.171	-6.833	0.228	2.952	0.439
47.25	-45.076	-6.115	0.267	2.882	0.391
63.00	-43.525	-5.417	0.292	2.783	0.346
78.75	-41.611	-4.747	0.308	2.661	0.304
94.50	-39.398	-4.109	0.302	2.519	0.263
110.25	-36.925	-3.508	0.287	2.361	0.224
126.00	-34.209	-2.948	0.263	2.187	0.188
141.75	-31.256	-2.432	0.233	1.999	0.156
157.50	-28.074	-1.965	0.197	1.795	0.126
173.25	-24.759	-1.549	0.158	1.583	0.099
189.00	-21.436	-1.185	0.124	1.371	0.076
204.75	-18.152	-0.873	0.094	1.161	0.056
220.50	-14.947	-0.612	0.070	0.956	0.039
236.25	-11.860	-0.401	0.050	0.758	0.026
252.00	- 8.907	-0.238	0.032	0.570	0.015
267.75	- 6.095	-0.120	0.018	0.390	0.008
283.50	- 3.457	-0.045	0.009	0.221	0.003
299.25	- 1.095	-0.009	0.002	0.070	0.001
315.00	0	0	0	0	0

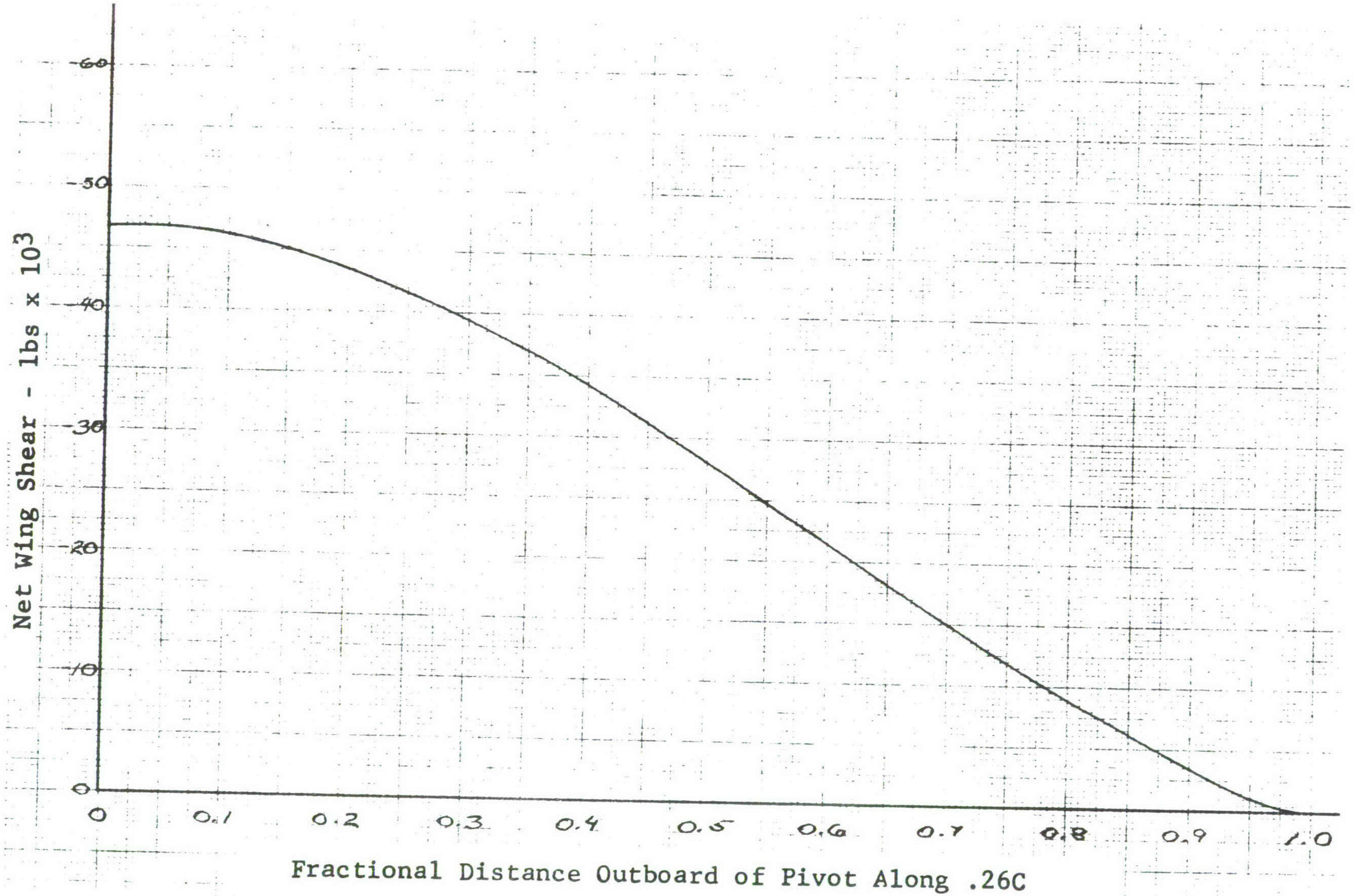


Figure 26
Final Flight Loads
Wing Spanwise Distribution of Net Shear
Condition F702A $n_z W$ = -218,000

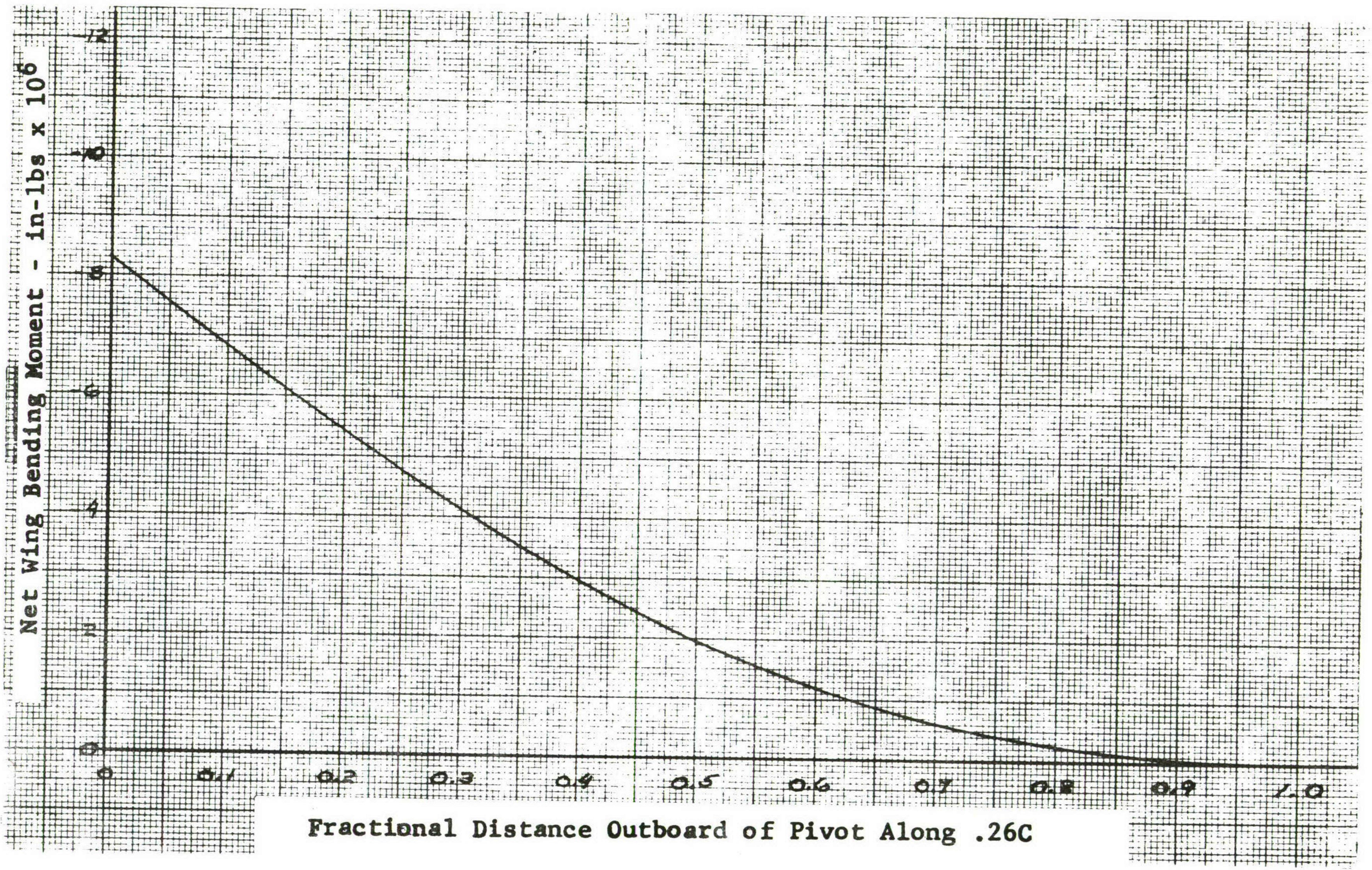


Figure 27
Final Flight Loads
Wing Spanwise Distribution of Net Bending Moment
Condition F702A $n_z W$ = -218,000

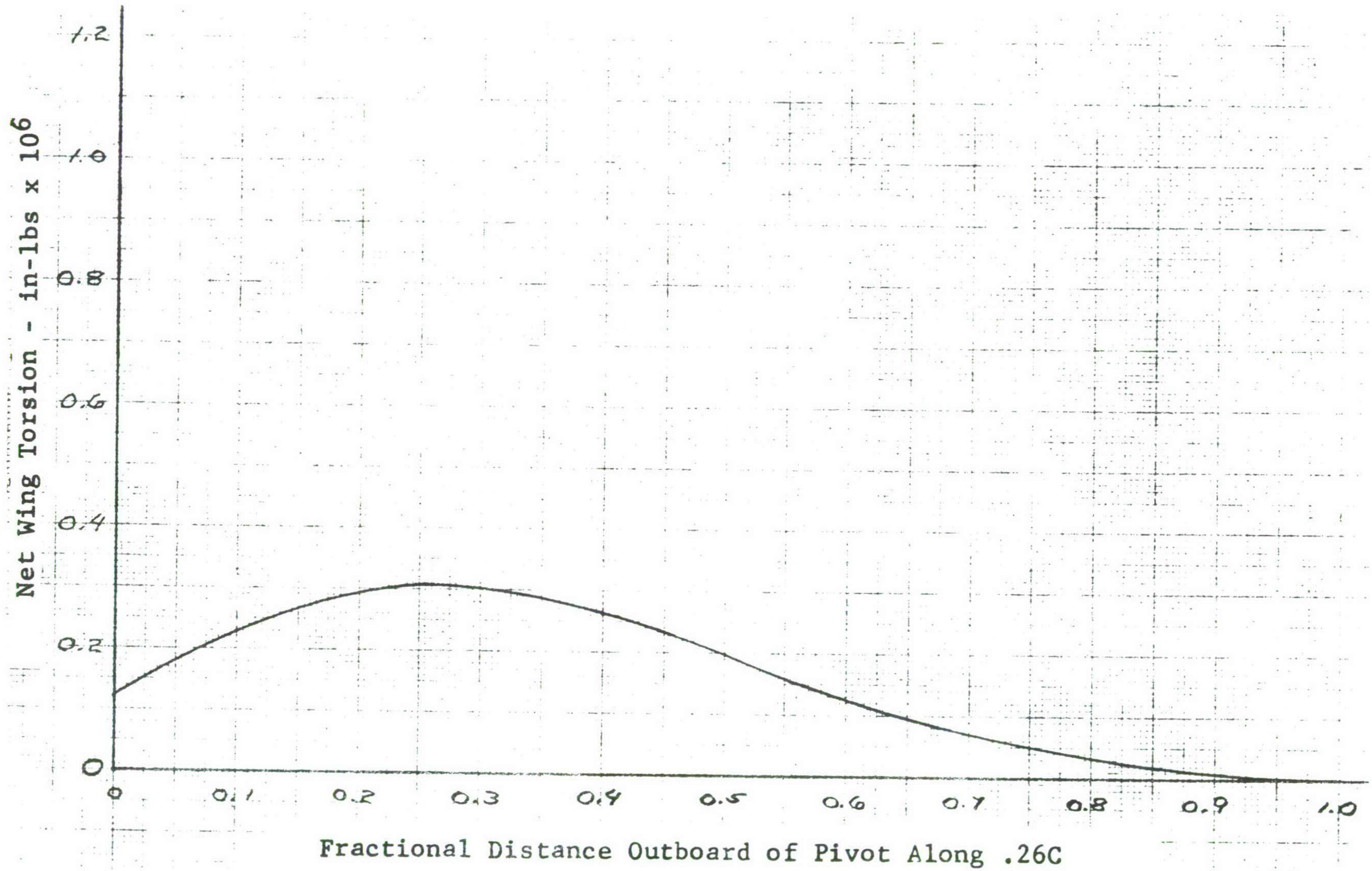


Figure 28
Final Flight Loads
Wing Spanwise Distribution of Net Torsion
Condition F702A $n_z W = -218,000$

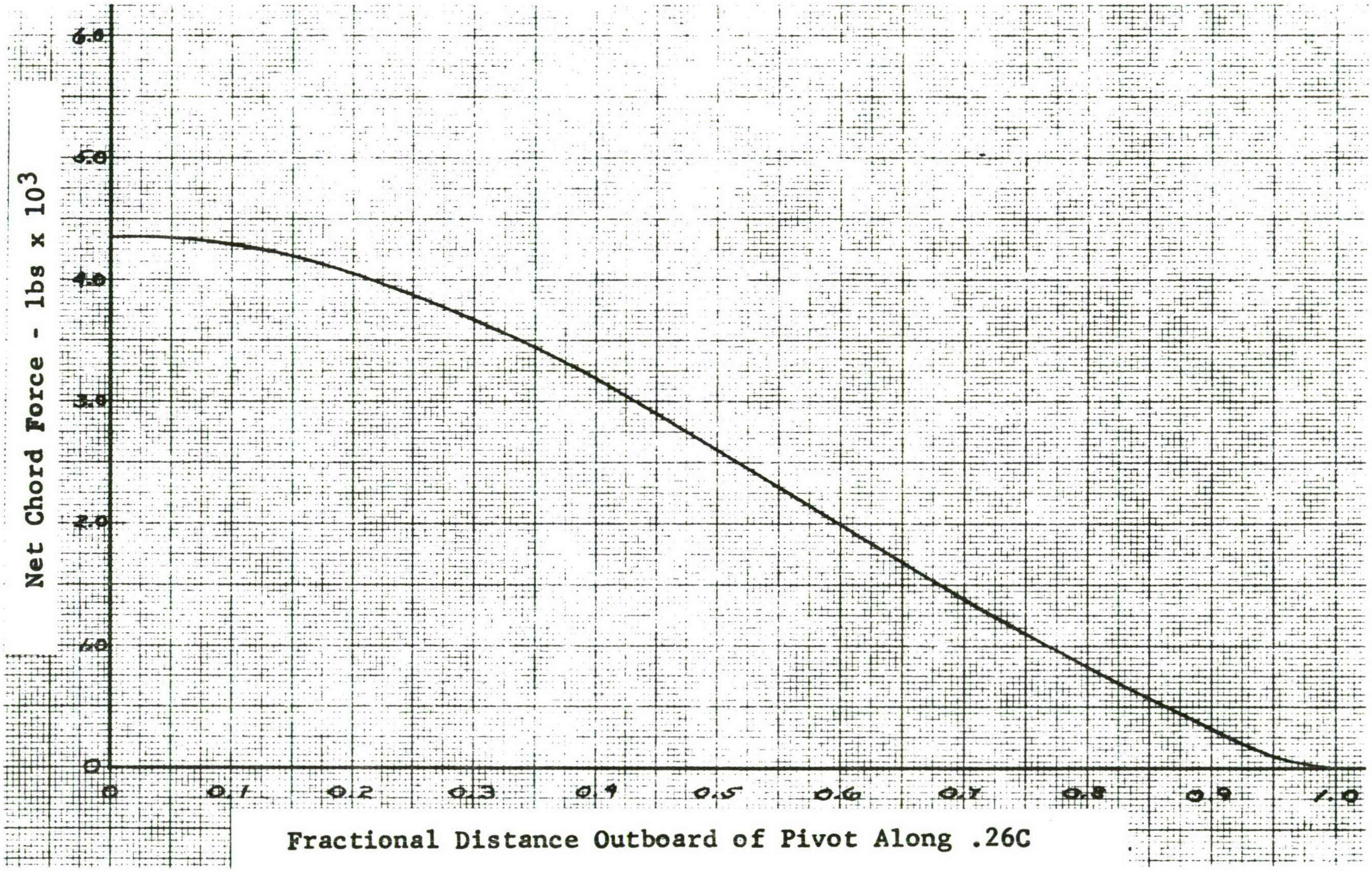


Figure 29

Final Flight Loads
Wing Spanwise Distribution of Net Chord Force
Condition F702A n_zW = -218,000

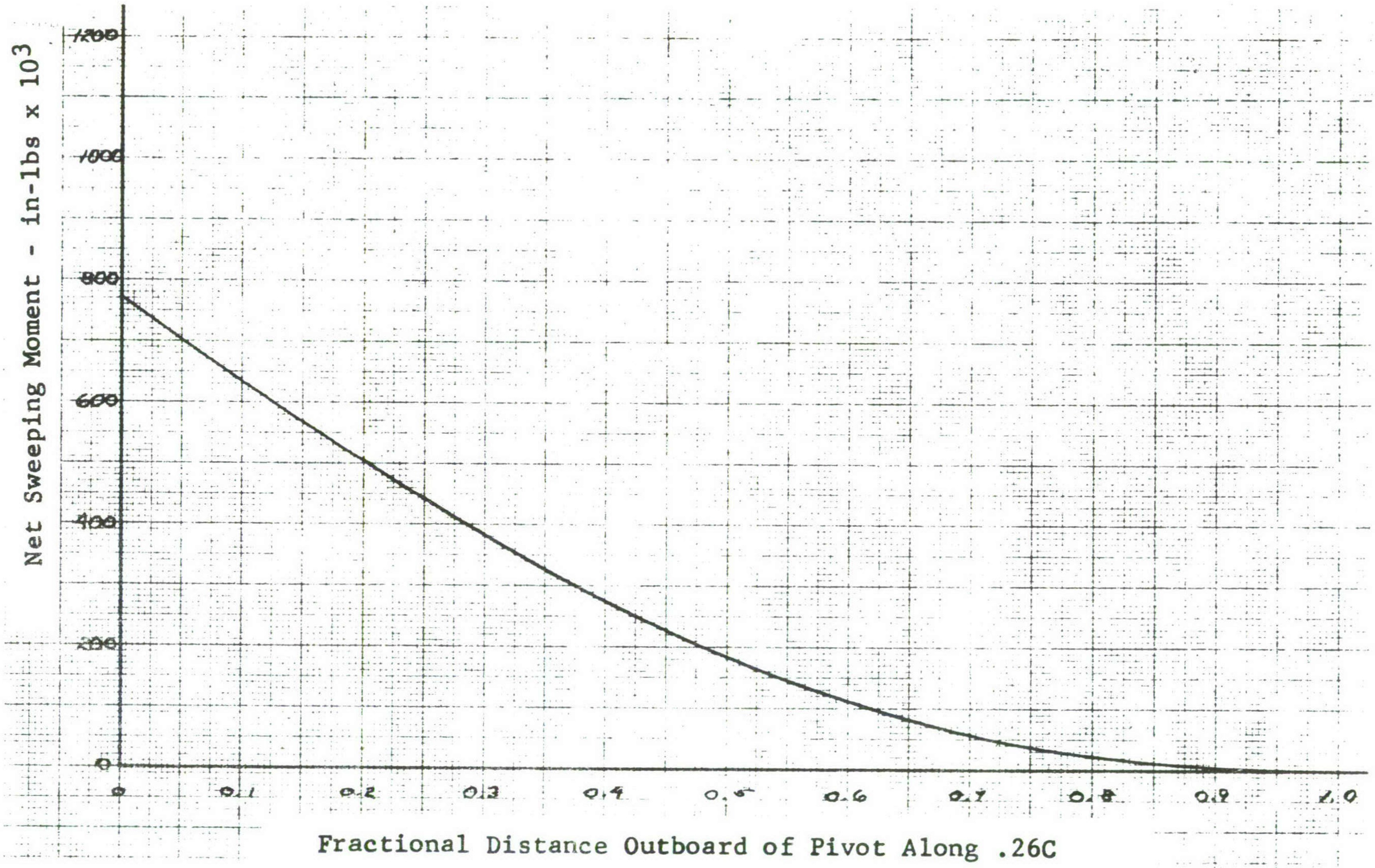


Figure 30
Final Flight Loads
Wing Spanwise Distribution of Sweeping Moment
Condition F702A $n_z W$ = -218,000

Table XVII

MAXIMUM FLAP TRACK LOADS AT THE REAR SPAR

CONDITION F101A

TRACK NUMBER	VERTICAL SHEAR (LBS)	BENDING MOMENT (IN-LBS)	LIMIT ALLOWABLE BENDING MOMENT (IN-LBS)	BENDING MOMENT % LIMIT
1	5,250	216,400	286,000	75.7
2	9,720	347,000	385,000	90.1
3	6,860	205,200	284,000	72.2
4	4,240	106,000	146,000	72.6
5	1,140	22,900	59,000	38.8

NOTE: Shear is at rear spar and normal to the wing plane. Bending moment is about the rear spar.

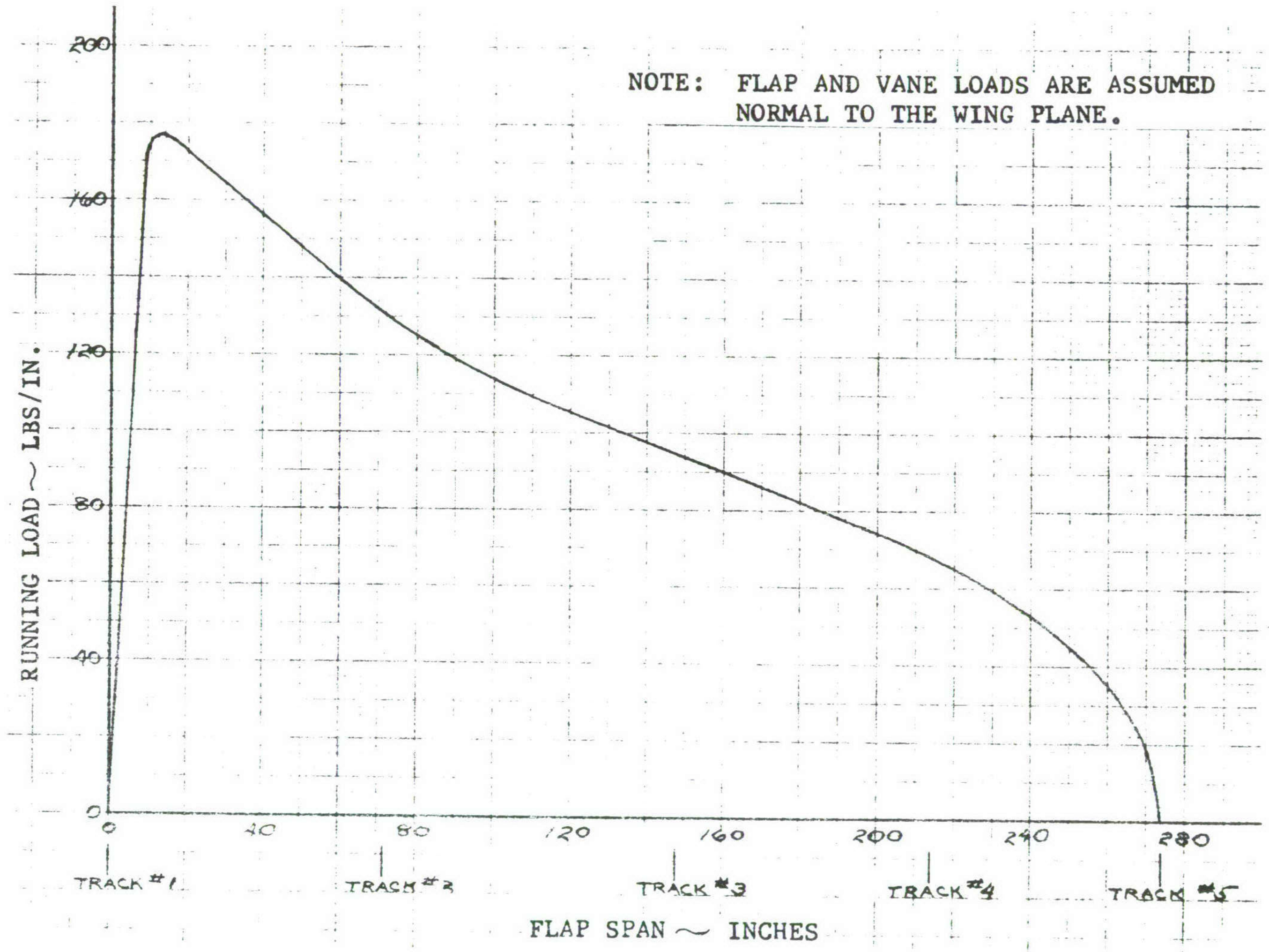


Figure 31
Flap Plus Vane Spanwise Running Load Distribution
Condition F101A

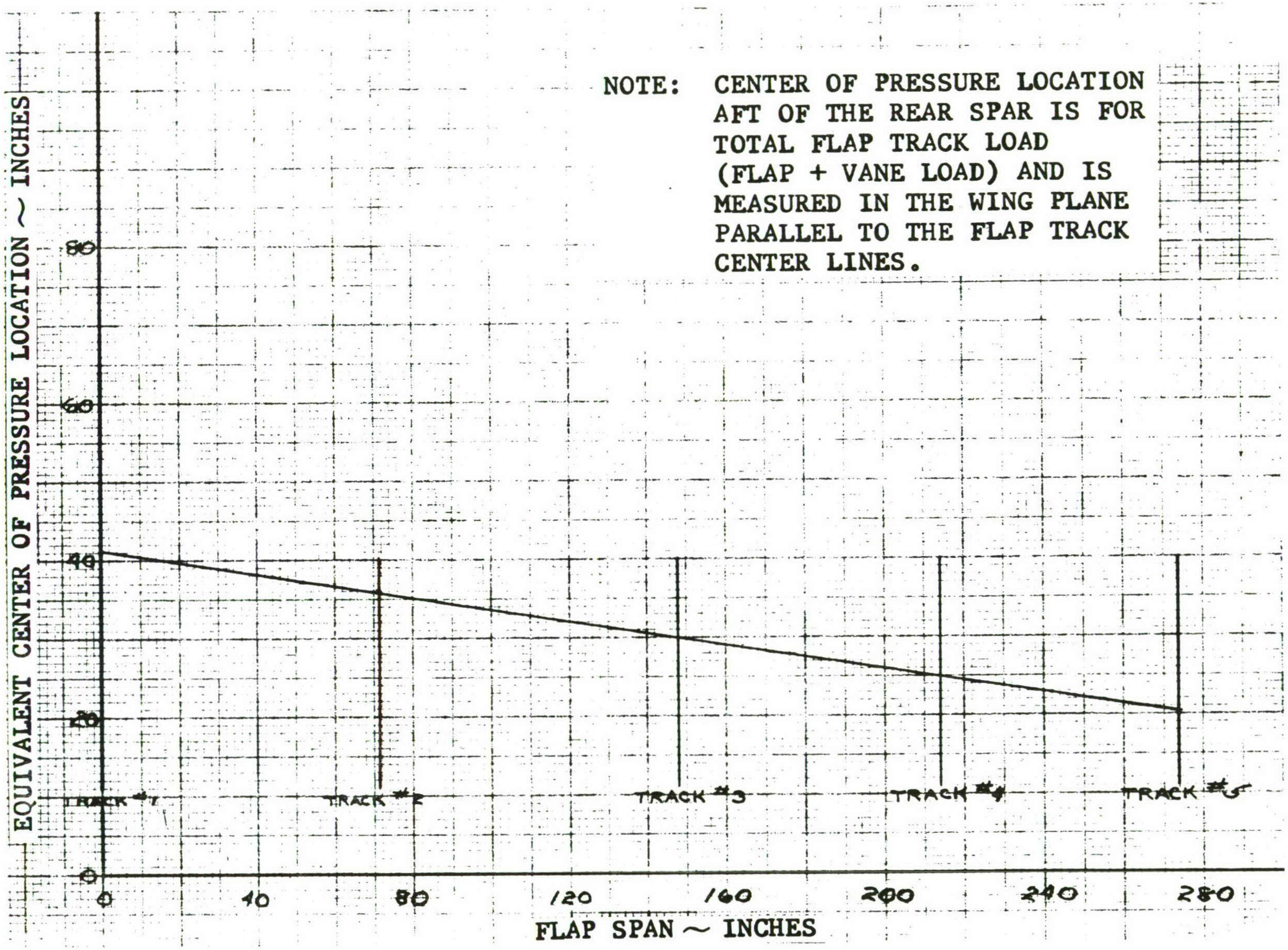


Figure 32
Equivalent Flap Track Center of Pressure Location Aft of Rear Spar vs. Flap Span
Condition F101A

Table XVIII

MAXIMUM SLAT TRACK BENDING MOMENTS[1]

$\Lambda = 16^{o}$, $\delta_F = 30^{o}$, A/S = 277 KCAS, h = Sea Level,
$n_Z W$ = 320,000 Lbs., $\alpha = 18.0^{o}$, $\delta_e = -18.5^{o}$

TRACK	BENDING[2] MOMENT (IN-LBS)	LIMIT ALLOWABLE BENDING MOMENT (IN-LBS)	% LIMIT ALLOWABLE
1-Inb'd	22,360	62,200	35.9
1-Outb'd	33,410	49,500	67.5
2-Inb'd	30,160	39,000	77.3
2-Outb'd	20,930	33,200	63.0
3-Inb'd	18,460	21,900	84.3
3-Outb'd	18,200	21,200	85.8
4-Inb'd	13,780	17,300	79.6
4-Outb'd	7,960	11,900	66.9

NOTES: (1) These loads do not occur at condition F101A. Slat loads at condition F101A are lower.

(2) The slat track moments and allowables are referenced to the instrumentation locations defined on page 109 of MRTP-12-529, F-111A No. 13 and No. 75 Structural Flight Test Programs Instrumentation, dated 27 May 1969.

Table XIX

FIXED PYLON DESIGN CONDITIONS (ULTIMATE)

	F_X (+ FWD)	F_Y (+ OBD) LBS	F_Z (+ UP)	M_X (+ W.T. UP)	M_Y (+ N. UP) IN-LBS	M_Z (+ N. OBD)
INBOARD FIXED						
(A)	- 4743	- 32786	38021	979105	615004	152414
(B)	- 4274	- 41141	624	1254560	136376	304958
(C)	14858	- 18989	- 40035	636871	- 1842613	292077
OUTBOARD FIXED						
(A)	2359	293	- 41685	- 19612	- 860298	- 28412
(B)	- 3618	- 41833	5340	1284178	166996	333153

NOTE: These conditions reflect F-111 static test ultimate load capability as reported in report 12A6270.

Reference point for loads is on lower surface on a vertical line midway between forward attachment bolts.

F_z = - 44,258 + 36,300 lbs, Positive Acting Up
F_y = - 11,400 + 66,570 lbs, Positive Acting Outboard
F_x = - 18,150 + 2,730 lbs, Positive Acting Forward
M_z = - 20,866 + 840,000 in-lbs, Positive Acting Nose Outboard
Note: All forces act on wing lower surface at pylon center line
(Axis of post for pivot pylons)

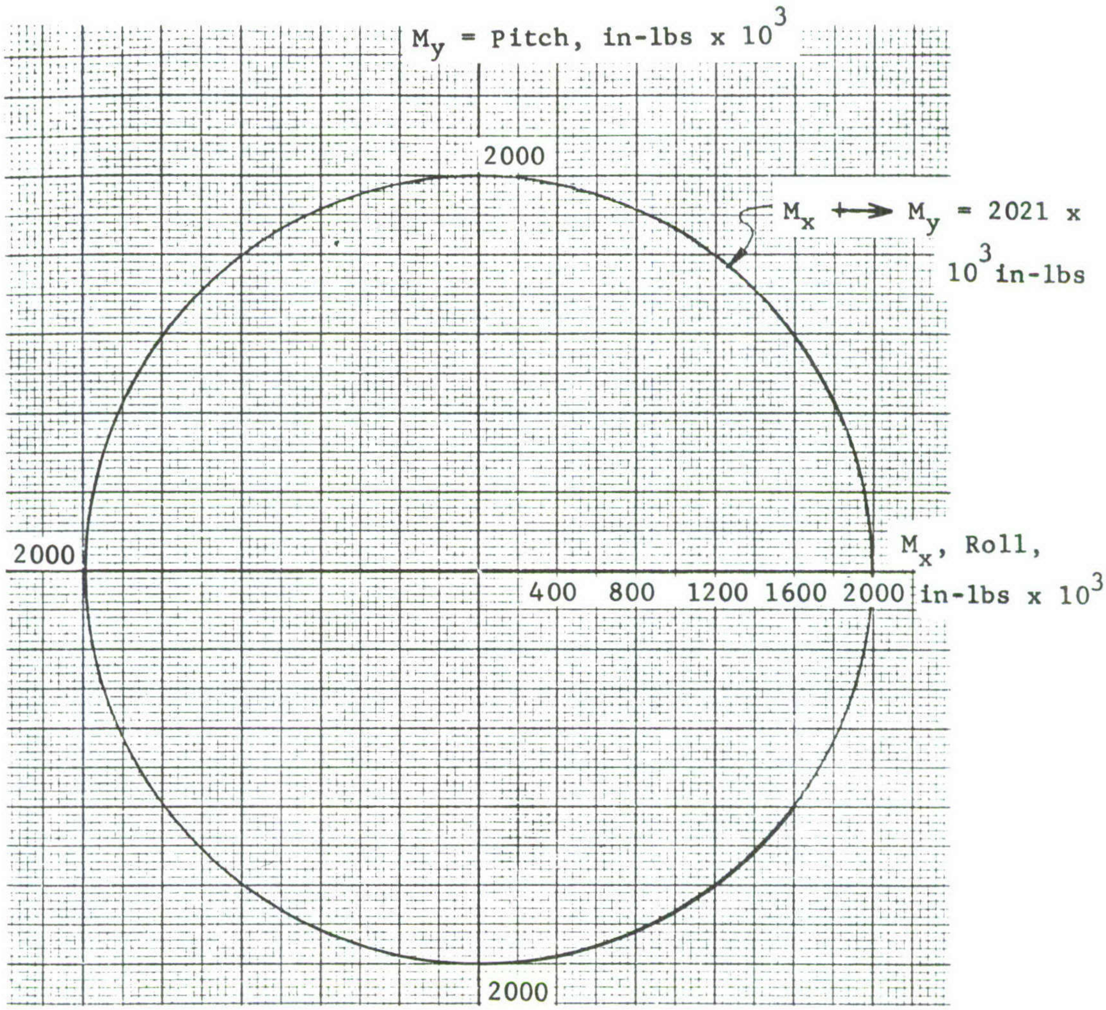


Figure 33 Pivot Pylon(s) Design Conditions (Ultimate)

(Loadings shown must be satisfied individually and collectively)

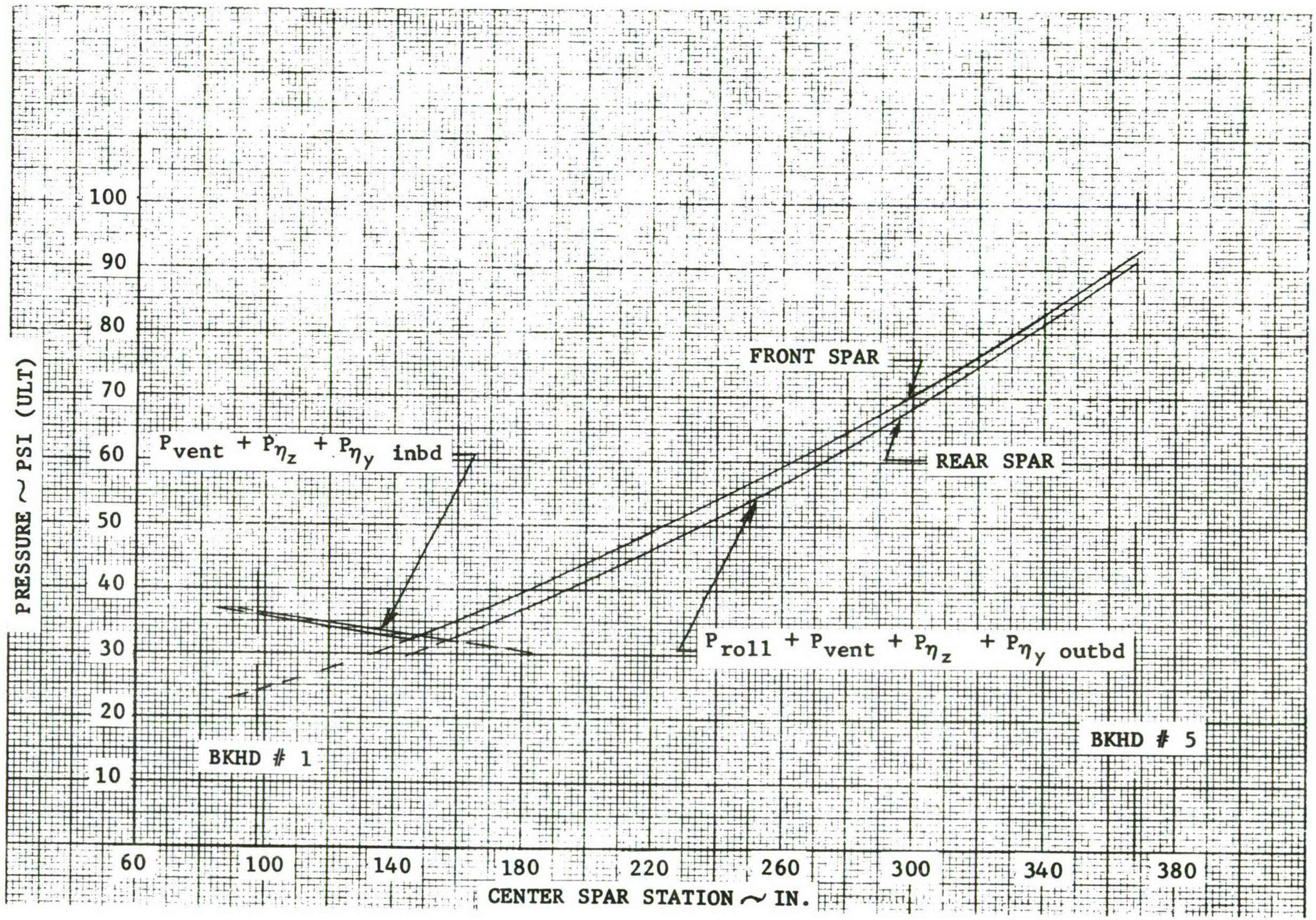


Figure 34
Fuel Tank Pressure Distributions

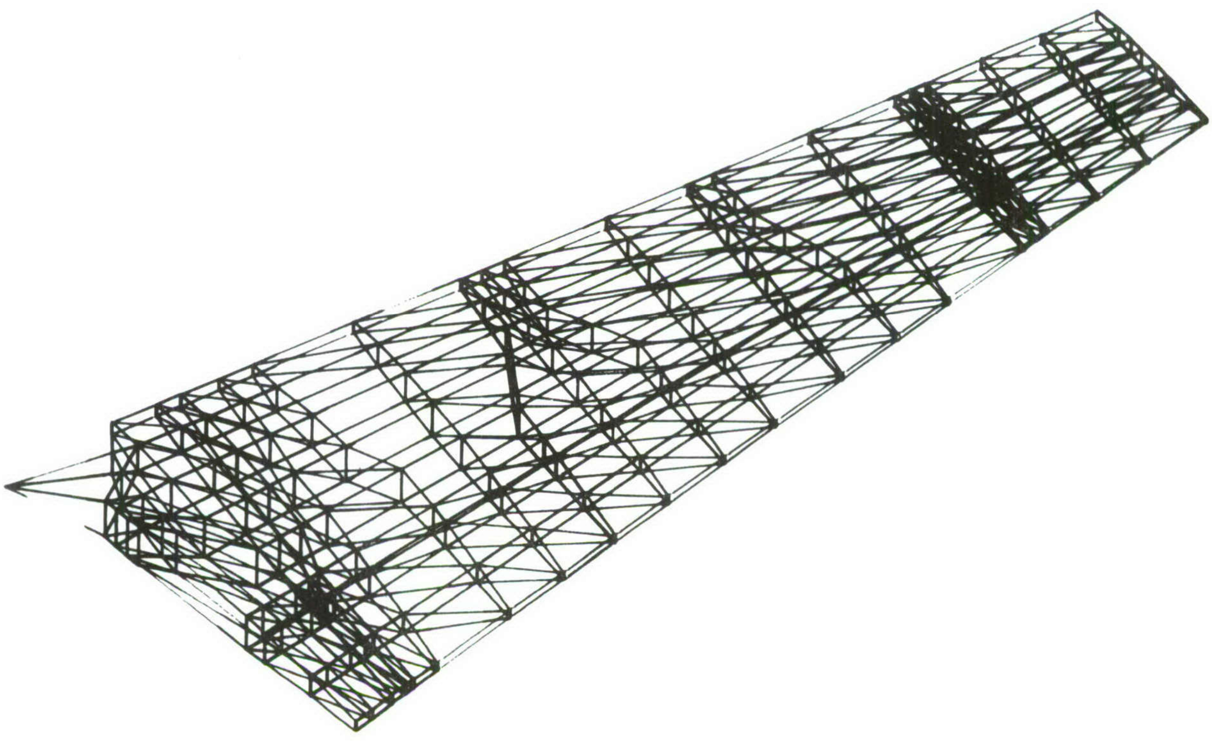


Figure 35

Math Model of Right Hand Wing for
Internal Loads Determination

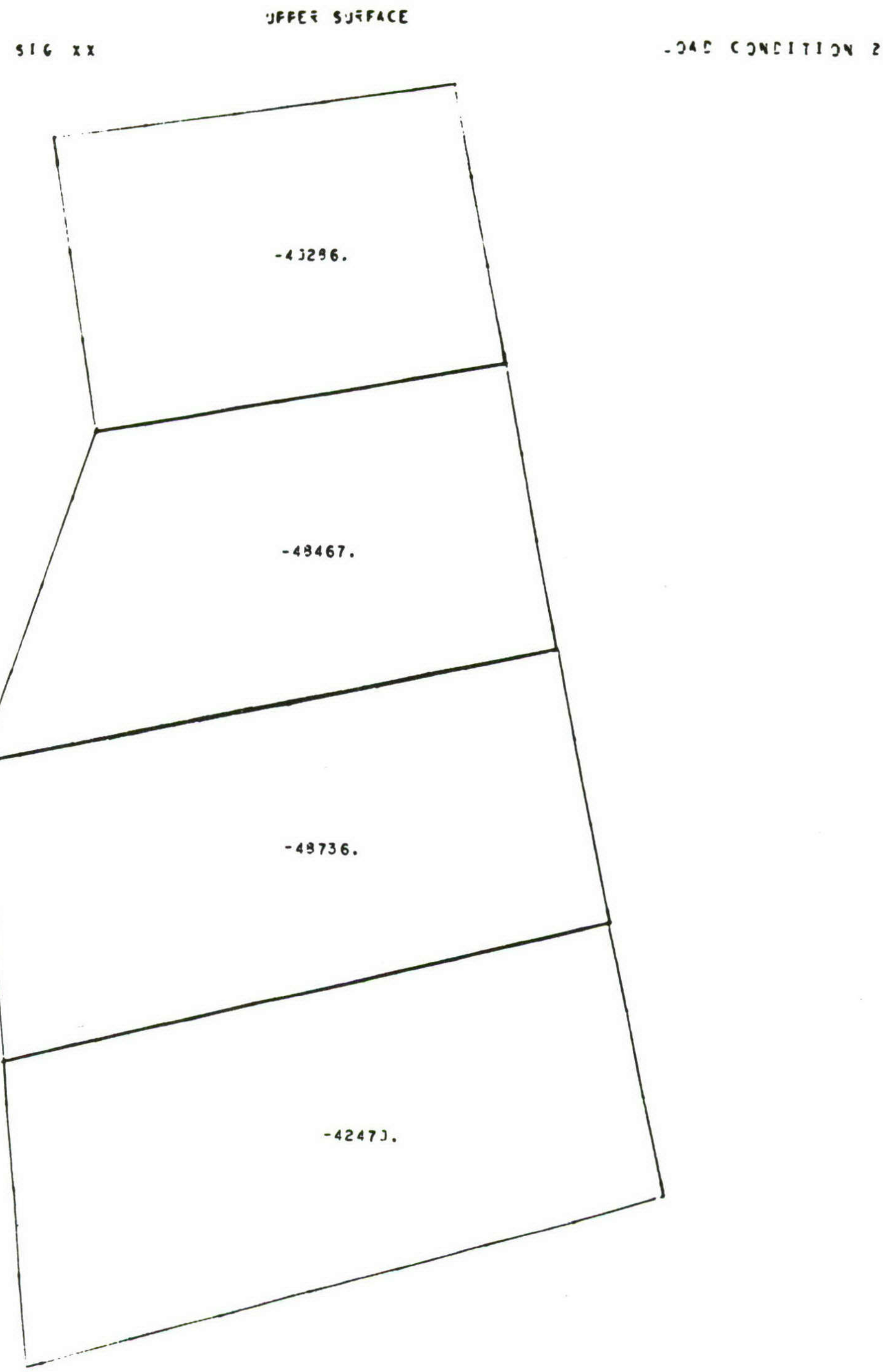


Figure 36 Loads Model at CSS 140
Upper Surface, Load Condition 2

Figure 37 Loads Model at CSS 140
Lower Surface, Load Condition 2

Figure 38   Loads Model at CSS 140
Lower Surface, Load Condition 2

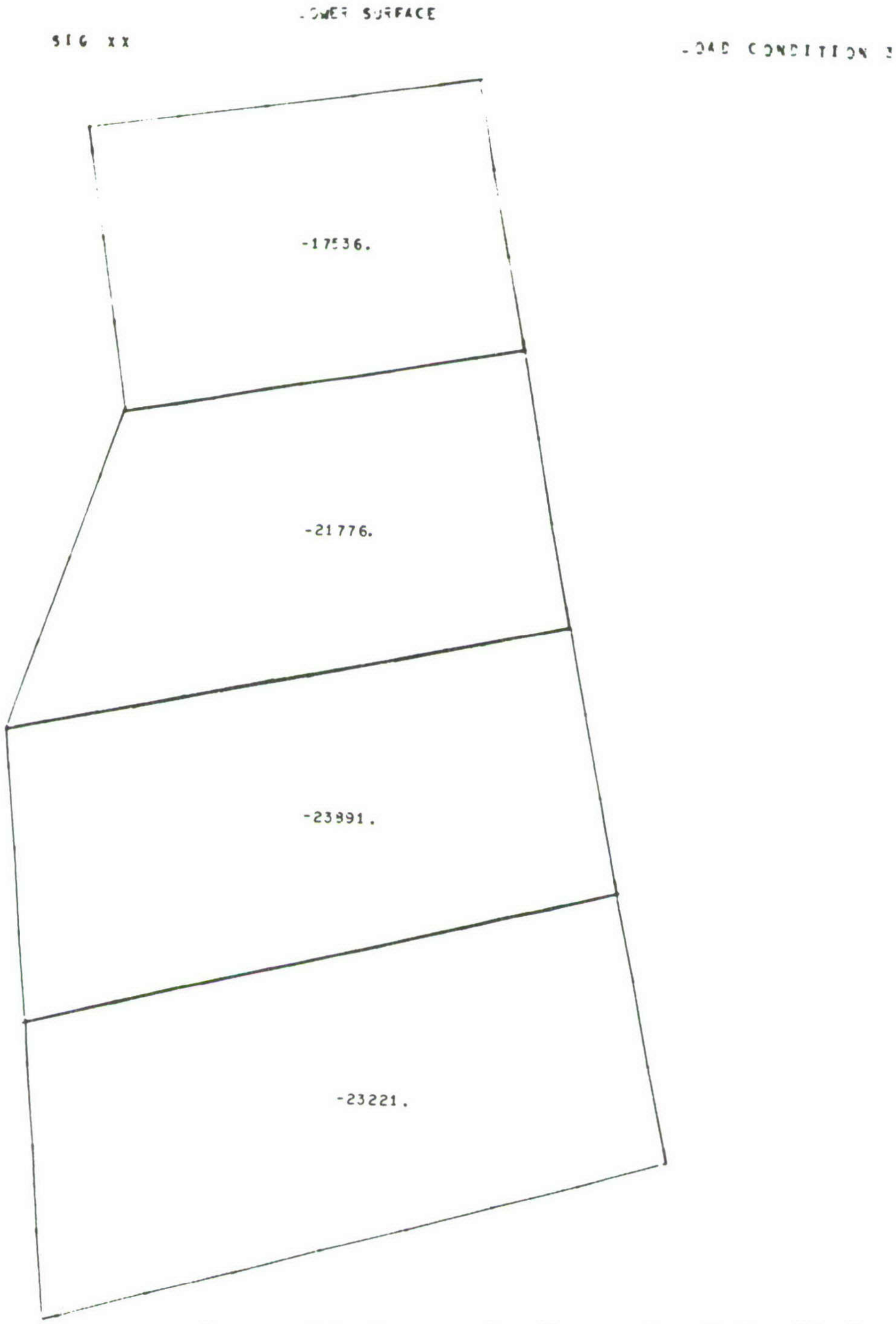
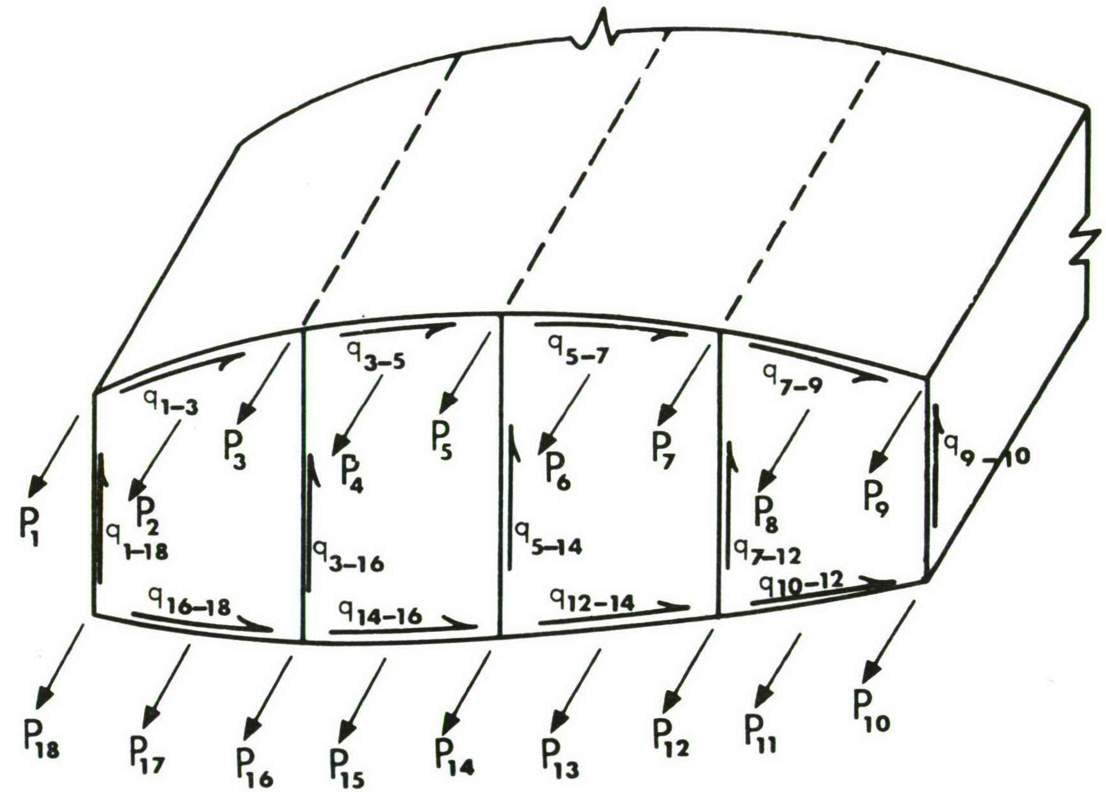


Figure 39 Lower Surface, Load Condition 3
Loads Model at CSS 140



VIEW LOOKING INBOARD
AT SECTION OF LEFTHAND WING

POSITIVE APPLIED LOADS SHOWN

Figure 40 Key to Wing Load Designations

Table XX F-111F WING CRITICAL DATA (LBS,ULT.)
BASELINE CROSS-SECTION

CSS	COND	P_1	P_2	P_3	P_4	P_5	P_6	P_7	P_8	P_9
340	F101A	-1886	-3754	-1660	-5091	-1999	-6786	-2165	-6082	-3776
↕	F400A	-2362	-4452	-1944	-5874	-2235	-7352	-2347	-6580	-4107
	F401A	878	1571	602	1566	579	1583	525	1396	1001
340	F702A	1228	2357	984	2937	1108	3619	1168	3200	2115
140	F101A	-46379	-314874	-46809	-350154	-29975	-335664	-41989	-130096	-30676
↕	F400A	-52427	-354025	-52109	-386678	-32987	-366660	-45421	-139438	-32962
	F401A	25212	174097	25668	192148	16426	182952	22715	70584	17478
140	F702A	24065	160769	23517	173886	14731	163296	20139	61934	14765
		P_{18}	P_{17}	P_{16}	P_{15}	P_{14}	P_{13}	P_{12}	P_{11}	P_{10}
340	F101A	3350	4099	1432	4599	1562	5199	2030	4446	2808
↕	F400A	4352	5085	1716	5256	1759	5665	2175	4720	2977
	F401A	-2059	-2125	-628	-1606	-480	-1086	-387	-684	-489
340	F102A	-2163	-2581	-851	-2628	-868	-2716	-1072	-2326	-1544
140	F101A	63318	324000	36675	347010	57148	339879	31226	113160	37541
↕	F400A	70193	360450	40638	382518	62785	371457	34058	122672	41305
	F401A	-36976	-187920	-20809	-192873	-30992	-181158	-16251	-57400	-19306
140	F702A	-30653	-158760	-18016	-170277	-28039	-167031	-15460	-56744	-19690

A / IN^2	CSS140	CSS340
1	1.39	.54
2	8.33	.87
3	1.11	.34
4	7.94	.98
5	.65	.33
6	7.56	1.13
7	1.00	.34
8	3.46	1.00
9	1.00	.63
10	1.32	.45
11	3.28	.68
12	.81	.30
13	8.31	.78
14	1.33	.23
15	8.07	.73
16	.85	.24
17	8.10	.76
18	1.71	.69

(SHEAR FLOW, LB/INCH, ULTIMATE)

CSS	COND	q_{1-3}	q_{3-5}	q_{5-7}	q_{7-9}	q_{9-10}	q_{10-12}	q_{12-14}	q_{14-16}	q_{16-18}	q_{1-18}	q_{3-16}	q [illegible]-14	q_{7-12}
140	F101A	-878	-2140	-3581	-2082	+1543	+2158	+4540	+2189	+487	+2176	+2006	+1802	+1891
	F400A	+47	-1381	-3032	-1720	+1103	+1807	+3795	+1470	-332	+3163	+2321	+1949	+1783
	F401A	-989	-424	+1207	+361	-55	-373	-1061	+64	+2787	-2527	-1425	-962	-605
	F702A	-234	-421	978	+544	-232	-602	-1402	-287	+487	-1635	-1039	-792	-605
340	F101A	+204	+145	+17	-144	+343	+57	+17	-34	-75	+491	+350	+321	+288
	F400A	+234	+174	+27	-163	+378	+62	+7	-59	-101	+582	+400	+363	+322
	F401A	-194	-209	-130	-26	-43	+34	+89	+120	+118	-325	-179	-145	-105
	F702A	-188	-182	-102	+19	-125	+40	+93	+138	+137	-382	-235	-198	-155

Table XXI

UPPER SURFACE SPAR CAP AND PANEL LOADS
BASELINE FINITE ELEMENT LOADS

n \ CSS	99	107	118	140	193	210	233	250	268	292	340
1	30200	45200	51300	52400	33900	37100	26600	19800	16200	11300	2360
2	603000	492000	420000	354000	185000	140000	94000	77000	59500	27200	4450
3	18400	25900	28800	52100	17500	16600	13700	13500	10800	8400	1950
4	651000	601000	480000	386700	229000	185000	132000	100000	64500	40300	5900
5	21200	31100	31200	33000	17200	17700	15700	15500	12500	9000	2250
6	448000	455000	460000	366700	219000	185000	143000	112000	69500	44700	7350
7	12900	28900	32500	45400	16600	17900	16000	15000	12500	8900	2350
8	133000	103000	126000	139400	178000	140000	94000	75000	53000	18100	6600
9	4020	15800	26100	33000	28500	30600	27400	23800	20500	14100	4100

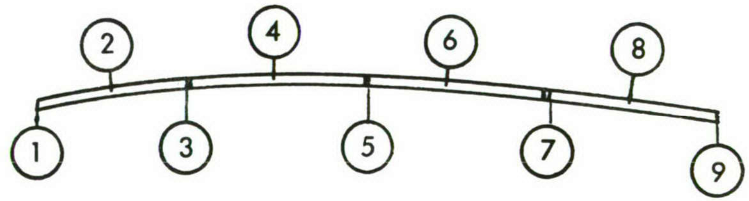
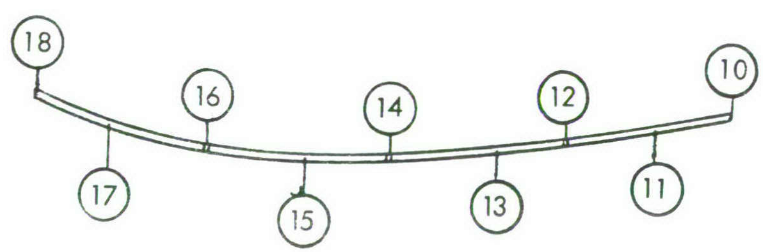


Table XXII

LOWER SURFACE LOAD DISTRIBUTION
BASELINE FINITE ELEMENT
LOADS

n \ CSS	99	107	118	140	193	210	233	250	268	292	340
18	28000	38600	49800	74500	33400	45300	31400	21200	29300	18700	4400
17	608000	546000	366000	360000	224000	147000	115000	93500	56400	32100	5200
16	16500	19000	20000	43000	20600	26400	19800	11800	15400	8620	1720
15	722000	780000	710000	382000	239000	162000	129000	93500	61200	38300	5300
14	18000	23400	21900	66500	23800	26600	21600	12500	16100	8800	1760
13	480000	386000	363000	372000	195000	154000	111000	109000	58200	36800	5600
12	14200	31200	32400	36200	24000	24800	19800	11800	13600	8550	2200
11	125500	112800	117000	123000	163000	120000	93000	52500	48700	24700	4800
10	5400	18100	27600	43800	45100	42200	37000	26400	22300	13900	3000



V.2 SCREENING PROCEDURES

Of the many structural concepts generated during the early phases of the program, one hundred and thirty-three (133) were proposed for further development and evaluation as complete wing cross-sections and, subsequently, as analytical assemblies. Each concept was assigned a number for identification and submitted as a preliminary drawing. To compare the weight-saving potential of the competing concepts, a computerized screening procedure was developed for estimating surface panel weights. The screening procedure incorporates an iterative weight minimization scheme which utilizes Ramberg-Osgood simulations of the material stress-strain curves. Well over one hundred (100) candidate surface panel concepts have been compared in this manner. Panel concept weights are affected by the following considerations:

- Material properties
- Load level (High loads @ CSS140, low loads @ CSS 340)
- Load type (Upper surface panel weights reflect compression load requirements; lower surface panel weights reflect tension load requirements.
- Panel size (Wide column lengths and plate widths)
- Panel cross-section (Such as honeycomb sandwich, truss core or blade stiffened skin).
- Damage tolerance category (Fail-safe, safe crack growth and holes vs hole-free).

The calculated weights for the panel concepts are shown in Tables V2-1 and V2-2. Definitions of terms used in the screening weight tables are as follows:

Wt_{TOT} = Total weight of skin panel and spar cap load carrying material in lbs per inch of span.

W_{STATIC} = Weight based on ultimate static load consideration on lower surface.

K_{σ} = Allowable stress reduction factor imposed by fatigue and/or damage tolerance requirements.

FS: = denotes fail-safe structure without holes

SCG: = denotes slow crack growth (non-fail-safe) structure without holes

FSH: = denotes fail-safe structure with holes

SCGH: = denotes slow crack growth structure with holes

The screening weights presented in Tables V2-1 and V2-2 constitute first-iteration sizings of surface panel concepts based on optimum panel cross-sections consistent with wing bending requirements. Shear web weight requirements are not included. Nor are fastener weights and secondary support structure weights. Thus, the indicated weights were considered only as minimum weight potentials for the various structural concepts. Those concepts which were selected for further development were integrated into cross section drawings and were subsequently sized and weighed in detail to reflect the many secondary considerations associated with realistic structural weights during the definition of the analytical assemblies.

Table XXIII

WING SURFACE PANEL CONCEPT WEIGHT ESTIMATES
(CSS 140 - LOWER SURFACE)

Concept No.	Concept Description	Materials	Damage Mode	W_{STATIC}	K_{σ}	Wt_{TOT}
610-012	Modified Triangular Core	Al 7050-T76	FS	2.54	1.00	2.54
610-012	Modified Triangular Core	Al 7050-T76	SCG	2.54	1.24	3.15
610-021	Multiple Rectangular Tube	Ti 6Al-4V (Ann.)	FS	2.05	1.00	2.05
610-021	Multiple Rectangular Tube	Ti 6Al-4V (Ann.)	FSH	2.05	1.17	2.40
610-021	Multiple Rectangular Tube	Ti 6Al-4V(Ann.)	SCG	2.05	1.21	2.48
610-021	Multiple Rectangular Tube	Ti 6Al-4V (Ann.)	SCGH	2.05	1.21	2.48
610-021	Multiple Rectangular Tube	Ti 8-8-2-3	FS	1.73	1.00	1.73
610-021	Multiple Rectangular Tube	Ti 8-8-2-3	FSH	1.73	1.64	2.84
610-021	Multiple Rectangular Tube	Ti 8-8-2-3	FS	1.73	1.64	2.84
610-021	Multiple Rectangular Tube	Ti 8-8-2-3	SCGH	1.73	1.72	2.97
610-032	Y-Tee Stiffened Skin	Ti 8-8-2-3	FS	1.73	1.00	1.73
610-032	Y-Tee Stiffened Skin	Ti 8-8-2-3	SCG	1.73	1.64	2.84
610-034	Triangular Truss Core	Ti 6Al-4V (Ann.)	FS	2.06	1.00	2.06
610-034	Triangular Truss Core	Ti 6Al-4V (Ann.)	SCG	2.06	1.26	2.60
610-034	Triangular Truss Core	Ti 8-8-2-3	FS	1.73	1.00	1.73
610-034	Triangular Truss Core	Ti 8-8-2-3	SCG	1.73	1.64	2.84
610-034	Triangular Truss Core	Al 7050-T76	FS	2.54	1.00	2.54
610-034	Triangular Truss Core	Al 7050-T76	SCG	2.54	1.24	3.15
610-101	Integral Tee Stiffened	Ti 6Al-4V (Ann.)	FS	2.05	1.00	2.05
610-101	Integral Tee Stiffened	Ti 6Al-4V (Ann.)	SCG	2.05	1.26	2.58

Table XXIII

(Contd)

Concept No.	Concept Description	Materials	Damage Mode	W_{STATIC}	K_{σ}	Wt_{TOT}
610-101	Integral Tee Stiffened	Ti 8-8-2-3	FS	1.73	1.00	1.73
610-101	Integral Tee Stiffened	Ti 8-8-2-3	SCG	1.73	1.64	2.84
610-105	Integral Blade	Al 7475-T7651	FS	2.44	1.00	2.44
610-105	Integral Blade	Al 7475-T7651	SCG	2.44	1.03	2.52
610-105	Integral Blade	Al 7475-T7651	FSH	2.44	1.13	2.76
610-105	Integral Blade	Al 7475-T7651	SCGH	2.44	1.13	2.76
610-105	Integral Blade	Ti 6Al-4V (Ann.)	FS	2.05	1.00	2.05
610-105	Integral Blade	Ti 6Al-4V (Ann.)	SCG	2.05	1.21	2.48
610-105	Integral Blade	Ti 6Al-4V (Ann.)	FSH	2.05	1.17	2.40
610-105	Integral Blade	Ti 6Al-4V (Ann.)	SCGH	2.05	1.21	2.48
610-105	Integral Blade	Ti 8-8-2-3	FS	1.72	1.00	1.72
610-105	Integral Blade	Ti 8-8-2-3	SCG	1.72	1.64	2.82
610-118	Integral Formed Bulb Tee	Al 7050-T76	FS	2.74	1.00	2.74
610-118	Integral Formed Bulb Tee	Al 7050-T76	SCG	2.74	1.24	3.40
610-118	Integral Formed Bulb Tee	Ti 6Al-4V	FS	2.05	1.00	2.05
610-118	Integral Formed Bulb Tee	Ti 6Al-4V	SCG	2.05	1.26	2.58
610-124	Hat Stiffened Skin	Ti 8-8-2-3	FS	1.75	1.00	1.75
610-124	Hat Stiffened Skin	Ti 8-8-2-3	SCG	1.75	1.64	2.87
610-124	Hat Stiffened Skin	Ti 6Al-4V (Ann.)	FS	2.05	1.00	2.05
610-124	Hat Stiffened Skin	Ti 6Al-4V (Ann.)	SCG	2.05	1.21	2.48

Table XXIII

(Contd)

Concept No.	Concept Description	Material	Damage Mode	W_{STATIC}	K_{σ}	Wt_{TOT}
610-124	Hat Stiffened Skin	Ti 6Al-4V (Ann.)	SCGH	2.05	1.21	2.48
610-124	Hat Stiffened Skin	Al 7050-T76	FS	2.48	1.00	2.48
610-124	Hat Stiffened Skin	Al 7475-T761	FS	2.44	1.00	2.44
610-124	Hat Stiffened Skin	Al 7475-T761	FSH	2.44	1.13	2.76
610-124	Hat Stiffened Skin	Al 7475-T76	SCG	2.44	1.03	2.51
610-124	Hat Stiffened Skin	Al 7475-T761	SCGH	2.44	1.13	2.76
610-128	Honeycomb Sandwich Panels	Al 7050-T76	FS	2.52	1.00	2.52
610-128	Honeycomb Sandwich Panels	Al 7050-T76	SCG	2.52	1.24	3.13
610-128	Honeycomb Sandwich Panels	Ti 8-8-2-3	FS	1.95	1.00	1.95
610-128	Honeycomb Sandwich Panels	Ti 8-8-2-3	SCG	1.95	1.64	3.20
610R-000	Sculptured Plate	Al 2024-T851	SCGH	2.50	1.70	4.25
610R-007	Full-Depth Core; Large Cell	Ti 8-8-2-3	SCG	2.20	1.64	3.16
610R-010	Honeycomb Panels - Composite Slugs	Ti 8-8-2-3	FS	1.87	1.00	1.87
610R-011	Honeycomb Panels - Channel Spar Splice	Ti 8-8-2-3	FS	1.74	1.00	1.74
610R-013B	Laminated Skin - Stepped Caps	Al 7050-T76	FS	2.30	1.00	2.30
610R-014	Full-Depth, Large Cell Core Laminated Skin	Ti 8-8-2-3	FS	1.85	1.00	1.85
610R-015B	Welded Space Truss Sub	Ti 6-4-(Ann.)	FS	1.79	1.00	1.79

Table XXIII

(Contd)

Concept No.	Concept Description	Material	Wt TOT
610-012	Modified Triangular	Al 7050-T76	3.00
610-012	Modified Triangular Truss Core	Ti 6Al-4V (Ann.)	2.36
610-021	Multiple Rectangular Tubes	Ti 6Al-4V (Ann.)	2.35
610-021	Multiple Rectangular Tubes	Ti 8-8-2-3	2.28
610-021	Multiple Rectangular Tubes	Ti 6Al-4V STA	2.16
610-032	Y-Tee Stiffened Skin	Ti 8-8-2-3	2.04
610-034	Triangular Truss Core	Al 7050-T76	2.86
610-034	Triangular Truss Core	Ti 6Al-4V STA	1.93
610-034	Triangular Truss Core	Ti 8-8-2-3	2.08
610-034	Triangular Truss Core	Ti 6Al-4V (Ann.)	2.23
610-101	Integral Tee Stiffened	Ti 6Al-4V STA	2.02
610-101	Integral Tee Stiffened	Ti 8-8-2-3	2.10
610-101	Integral Tee Stiffened	Ti 6Al-4V (Ann.)	2.32
610-105	Integral Blade Stiffened	Ti 6Al-4V STA	2.18
610-105	Integral Blade Stiffened	Ti 8-8-2-3	2.25
610-105	Integral Blade Stiffened	Ti 6Al-4V(Ann.)	2.33
610-105	Integral Blade Stiffened	Al 7050-T7651	2.87
610-118	Integral Formed Bulb Tee	Ti 6Al-4V (Ann.)	2.30
610-118	Integral Formed Bulb Tee	Al 7050-T76	2.85
610-118	Integral Formed Bulb Tee	Ti 6Al-4V STA	2.02

Table XXIII

(Contd)

Concept No.	Concept Description	Material	Wt TOT
610-124	Hat Stiffened Skin	Ti 6Al-4V STA	2.02
610-124	Hat Stiffened Skin	Ti 6Al-4V (Ann.)	2.30
610-124	Hat Stiffened Skin	Al 7050-T76	2.91
610-128	Honeycomb Sandwich Panels	Al 7050-T76	2.81
610-128	Honeycomb Sandwich Panels	Ti 6Al-4V STA	2.03
610-200	Laminated Plate (B = 9.5)	Ti 8-8-2-3	4.16
	Sculptured Plate Fixed Edg	Al 7050-T7651	3.06
610R-000	Baseline-Sculptured Plate	Al 2024-T851	3.38
610R-007	Full-Depth Core: Large Cell	Ti 8-8-2-3	2.38
610R-010	Honeycomb Panels	Ti 8-8-2-3	1.98
610R-011	Honeycomb Panels	Ti 6Al-4V STA	1.91
610R-013	Hat Stiffened Skin	Al 7050-T76	2.81
610R-014	Laminated Skin; Full Depth Core	Ti 6Al-4V STA	2.01
610R-014A	Space Truss-Welded Tube	Ti 6Al-4V STA	1.85
610R-028	Honeycomb Sandwich Panels	Al 7050-T76	2.81
610R-029	Sculptured Skin; Fixed Edges	Al 7050-T76	3.09

Table XXIV

WING SURFACE PANEL CONCEPT WEIGHT ESTIMATES
(WING CSS 340 - LOWER SURFACE)

Concept No.	Concept Description	Materials	Wt TOT
610-016	Modified Triangular Truss Core	Al 7050-T76	0.24
610-016	Modified Triangular Truss Core	Ti 6Al-4V (Ann.)	0.33
610-021	Multiple Rectangular Tubes	Ti 6Al-4V (Ann.)	0.32
610-034	Triangular Truss Core	Ti 6Al-4V (Ann.)	0.35
610-034	Triangular Truss Core	Al 7050	0.24
610-101	Integral Tee Stiffeners	Al 7475-T7651	0.19
610-101	Integral Tee Stiffeners	Ti 6Al-4V (Ann.)	0.28
610-105	Integral Blade Stiffeners	Al 7475-T7651	0.21
610-105	Integral Blade Stiffeners	Ti 6Al-4V(Ann.)	0.32
610-124	Hat Stiffened Skin	Al 7050-T76	0.24
610-124	Hat Stiffened Skin	Ti 6Al-4V (Ann.)	0.33
610-128	Honeycomb Sandwich Panel	Al 7050-T76	0.27
610R-104	Baseline-Sculptured Plate	Al 2024-T851	0.49
610R-100	Honeycomb Sandwich Panels	Al 7050-T76	0.42
610R-102	Adhesive Bonded Multi-Spar	Al 7050-T76	0.18
610R-103	Honeycomb Sandwich Panels	Ti 6Al-4V (Ann.)	0.50
610-118	Integral Formed Bulb Tee	Al 7475	0.23

Table XXIV

(Contd)

Concept No.	Concept Description	Material	Wt_{TOT}
610-016	Modified Triangular Truss Core	Al 7050-T76	0.29
610-021	Multiple Rectangular Tubes	Ti 6Al-4V STA	0.37
610-021	Multiple Rectangular Tubes	Ti 6Al-4V (Ann.)	0.38
610-034	Triangular Truss Core	Ti 6Al-4V (Ann.)	0.39
610-034	Triangular Truss Core	Al 7050	0.28
610-101	Integral Tee Stiffeners	Al 7050-T7651	0.26
610-101	Integral Tee Stiffeners	Ti 6Al-4V STA	0.31
610-105	Integral Blade Stiffeners	Al 7050-T7651	0.30
610-105	Integral Blade Stiffeners	Ti 6Al-4V STA	0.37
610-105	Integral Blade Stiffeners	Ti 6Al-4V (Ann.)	0.38
610-124	Hat Stiffened Skin	Al 7050-T76	0.28
610-124	Hat Stiffened Skin	Ti 6Al-4V (Ann.)	0.32
610-128	Honeycomb Sandwich Panels	Al 7050-T76	0.27
610-200	Laminated Plates	Al 7050-T76	0.45
610-200	Laminated Plates	Ti 8-8-2-3	0.78
610R-104	Baseline-Sculptured Plate	2024-T851	0.62
610R-101	Full-Depth Core Sandwich	Ti 6Al-4V STA.	0.22
610R-108	Full-Depth Core Sandwich	Ti 8-8-2-3	0.28
610R-109	Multiple Tension Stra/Inte.Stiff.	Ti 6Al-4V(Ann.)	0.43
610R-100	Ribbon Truss Upr Surf.Sandwich	Al 7050-T76	0.60

Table XXIV

(Contd)

Concept No.	Concept Description	Material	Wt TOT
610R-102	Adhesive Bonded Multi-Spar	Al-7050-T76	0.18
610R-103	Honeycomb Sandwich Panels	Ti 6Al-4V (Ann.)	0.49
610-118	Integral Formed Bulb Tee	Al 7475	0.30

V.2.1 Screening Procedure Demonstration Problem

Sample input and output data for the screening procedure are shown on the following pages. From the input data sheet it can be seen that the concept selected for sizing is a 2024-T851 aluminum alloy sculptured plate representative of the upper surface of the baseline wing at wing center spar station 140. The program provides for a considerable amount of flexibility due to the number of variables which may be considered. Primary variables include:

K_i = stress distribution factors

B_i = plate buckling widths

Index - stipulation for either plate buckling or wide column buckling

PLAS CAT = plasticity category. Provides for several options for plasticity reduction factors

D = increased panel depth thickness relative to baseline

L = column length when applicable

Tmin = minimum material gage

EA = structural efficiency factor. May be varied to reflect either simple support or fixed edges for plates.

EXP = exponent in plate buckling equations

P_i = element loads

F_y = design yield stress

TF_y = typical yield stress

$TF_{.7}$ and $TF_{.85}$ = secant intercept stresses for typical stress-strain curve

Included on the output data sheet are:

N = 45.20 = Rainberg-Osgood shape factor

$KH = 1.00$ = effective depth correction factor

P_i = element applied ultimate loads

$\overline{N}$ = plasticity reduction factor

T = required plate gage to prevent buckling

SIG_i = ultimate applied stress

A_i = element area required to support SIG_i

ρ = material density (Lb/In^3)

$PA_i = A_i \times SIG_i$

$DEL \ A_i = (P_i - PA_i)/SIG_i$

A_{MIN} = minimum spar cap area

$$ALC = \sum_{i=1}^{9} (A_i + DEL\ A_i + A\ MIN_i)$$

= total area of load-carrying material in upper (or lower) surface (in^2)

$WLC = \rho\ ALC$ = weight of load-carrying material in lbs per inch pf spar

The final upper surface weight for the demonstration problem is 3.37 lb per inch of span and corresponds to a total load carrying area of 33.67 in^2. This is slightly conservative since the minimum area required is 33.59 in^2 as shown by the print-out of the load carrying area iterations (ALC). The peak compression stress developed is 54500 psi (ultimate).

Table XXV

WING SURFACE CONCEPT SCREENING PROCEDURE
COMPRESSION LOAD CONDITION

GENERAL DYNAMICS
360 PROCEDURE WFH

CONVAIR AEROSPACE DIVISION
PROBLEM OC5278-36

FORT WORTH OPERATION
10/11/72

CONCEPT NO: BASELINE

CONCEPT TITLE: SCULPTURED PLATE (2024-T851)

WING CSS: 140 UPPER

LOAD COND: F400A COMPRESSION (ULT)

INPUT DATA

K1	K2	K3	K4	K5	K6	K7	K8	K9	
0.7420	0.8300	0.8830	0.9550	1.0000	0.9500	0.9050	0.7890	0.6500	Stress Distribution Factors

S1	S2	S3	S4	S5	S6	S7	S8	S9	
3.2000	14.0000	2.0000	13.3000	1.5000	12.4000	1.2500	13.7000	2.1800	Baseline Plate Element Widths

B1	B2	B3	B4	B5	B6	B7	B8	B9	
12.5000	12.5000	12.9000	13.3000	12.8500	12.4000	12.5500	12.7000	12.7000	Plate Buckling Widths

A1	A2	A3	A4	A5	A6	A7	A8	A9
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

INDEX	PLAS CAT	HM	D	L	A0	WF	T MIN
2.0000	2.0000	12.1600	0.0	12.0000	0.0	0.0158	0.0200

TC	AC	AB	AG	NF	WBL	EA	EXP
0.0	0.0	0.0	0.0	50.0000	2.6600	3.6200	3.0000

PM	P1	P2	P3	P4	P5	P6	P7	P8	P9	QM
0.	52430.	354000.	52110.	386700.	32990.	366700.	45400.	139400.	33000.	3030.

MATERIAL IS AL 2024

FTU = 0.	FSU = 36000.	E = 10700000.	DENSITY = 0.10000
FY = 58000.	TFY = 60000.	TF.7 = 60400.	TF.85 = 59200.
EC = 0.0	EB = 0.0	EG = 0.0	KS = 0.85000
KJ = 1.00000			

OUTPUT DATA

F.7 = 58386.66   N = 45.20   KH = 1.00

I	P	SIG	NT	NS	$\overline{N}$	T	A	PA	CELA	AMIN
1	52430.	40454.	1.0000	1.0000	1.0000	0.4040	1.2927	52294.	0.003	0.0
2	354000.	45252.	0.9998	1.0000	0.9999	0.4273	5.9818	270684.	1.841	0.0
3	52110.	48141.	0.9962	0.9999	0.9986	0.4551	0.9102	43819.	0.172	0.0
4	386700.	52067.	0.8909	0.9973	0.9572	0.4984	6.6288	345139.	0.798	0.0
5	32990.	54520.	0.5162	0.9797	0.7700	0.5494	0.8241	44931.	0.0	0.288
6	366700.	51794.	0.9115	0.9979	0.9656	0.4614	5.7219	296361.	1.358	0.0
7	45400.	49341.	0.9888	0.9997	0.9958	0.4489	0.5611	27684.	0.359	0.0
8	139400.	43016.	1.0000	1.0000	1.0000	0.4232	5.7982	249419.	0.0	0.204
9	33000.	35438.	1.0000	1.0000	1.0000	0.3841	0.8374	29677.	0.094	0.0

WLC = 3.37

ALC = 35.60
ALC = 33.97
ALC = 33.59
ALC = 33.67

V.3 SAMPLE CALCULATIONS FOR ANALYTICAL ASSEMBLIES

Analytical assemblies were sized by first applying a section depth magnification factor to the baseline finite element loads to account for differences in skin panel thicknesses. Peak allowable stresses were then determined for both the upper and the lower surfaces and the corresponding stress distributions defined in accordance with the stress distribution factors from the baseline math model. Element area requirements were then calculated consistent with the design loads and the allowable stresses. In addition, detail checks of the critical and upper and lower surface elements were performed to substantiate the allowable stress levels used in the element area calculations.

The general sizing process outlined above is illustrated by the sample calculations to follow. Analytical Assembly No. 610RA003 is used for the sample calculations. This assembly concept was subsequently expanded into full wing box concept 610RW001.

In Table XXVI the loads, stresses and element area requirements for Analytical Assembly No. 610RA003 are tabulated. Column headings for Table XXVI are defined as follows:

P_{O_U} = upper surface baseline element loads (lbs.).

P_{O_L} = lower surface baseline element loads (lbs.).

P_{UPR} = upper surface loads magnified by depth factor.

P_{LWR} = lower surface loads magnified by depth factor.

σ_{UPR} = upper surface stress distribution for 610RA003.

σ_{LWR} = lower surface stress distribution for 610RA003.

A_{UPR} = upper surface element area requirements for 610RA003.

A_{LWR} = lower surface element area requirements for 610RA003.

The critical compression element in the upper surface is element number 4. This element is a 7050-T76 aluminum honeycomb sandwich panel stressed to -63800 psi and controls the level of stresses in the upper surface in accordance with the stress distribution factors from the baseline math model. The peak compression

Table XXVI

ANALYTICAL ASSEMBLY NO. 610RA003

SURFACE AREA REQUIREMENTS

CSS 140

	ELEMENT	P_{OU}	P_{OL}	P_{UPR}	P_{LWR}	UPR	LWR	A_{UPR}	A_{LWR}
Column	1	2	3	4	5	6	7	8	9
Operation				1.025 2	1.025 3			4/6	5/7
Reference				▷1	▷1				
	1	-52430	70190	-53700	72000	-50000	60500	1.075	1.190
	2	-354030	360450	-363700	369000	-56100	65000	6.490	5.670
	3	- 52110	40640	-53400	41700	-59000	69500	.905	.600
	4	-326636	382520	-396000	393000	-63800	69200	6.200	5.680
	5	- 32990	62790	- 33800	64400	-67000	68500	.505	.940
	6	-366660	371460	-376000	320000	-63500	65000	5.920	5.850
	7	- 45420	34060	- 46500	35000	-60200	61400	.765	.570
	8	-139440	122670	-143000	125700	-53000	54400	2.700	2.310
	9	- 32960	41310	- 33800	42300	-44000	45800	.770	.920
								Σ25.33	Σ23.73

▷1 Section Depth Factor

stress of -67,000 psi occurs on element number five (5) which is not stability-critical since it is a spar cap element. A structural stability check of panel number four (4) is performed below:

<u>Basic data</u>:

G = 67000 psi = longitudinal shear modulus of Type 1B 5056 aluminum honeycomb core.

h_c = 1.00" = core thickness

t_f = .125" = gage of 7050-T76 aluminum alloy facing material

$E = 10.5 \times 10^6$ psi = 7050-T76 modulus of elasticity

μ = .33 = Poisson's ratio for facing material

B_4 = 13.3 = panel width, inches.

$\bar{\eta}$ = plasticity reduction for the effective modulus (Ref. Figure 41)

$$U = \frac{(h_c + t_f)^2}{h_c} \times G = \frac{(1 + .125)^2}{1.00}(67000) = 85000 \text{ lb/in}$$

= panel shear stiffness per inch

$$D = \frac{E t_f h^2{}_c}{2(1 - \mu^2)} = \frac{(10.5 \times 10^6)(.125)(1.00)^2}{2\left[1 - (.33)^2\right]} = 737000 \ \frac{\text{lb-in}^2}{\text{in}}$$

= panel bending stiffness per inch

$$J = \frac{B^2 U}{\pi^2 D} = \frac{(13.3)^2(85000)}{\pi^2(737000)} = 2.05$$

K_c = 1.82 = panel buckling constant

$$\frac{F_{cr}}{\bar{\eta}} = \frac{K_c U}{2 J t_f} = \frac{(1.82)(85000)}{(2)(2.05)(.125)} = 302000$$

F_{cr} = <u>69000</u> psi (Reference Figure 41)

Since σ_4 = -63800 psi (from Table XXVI) panel strength is adequate.

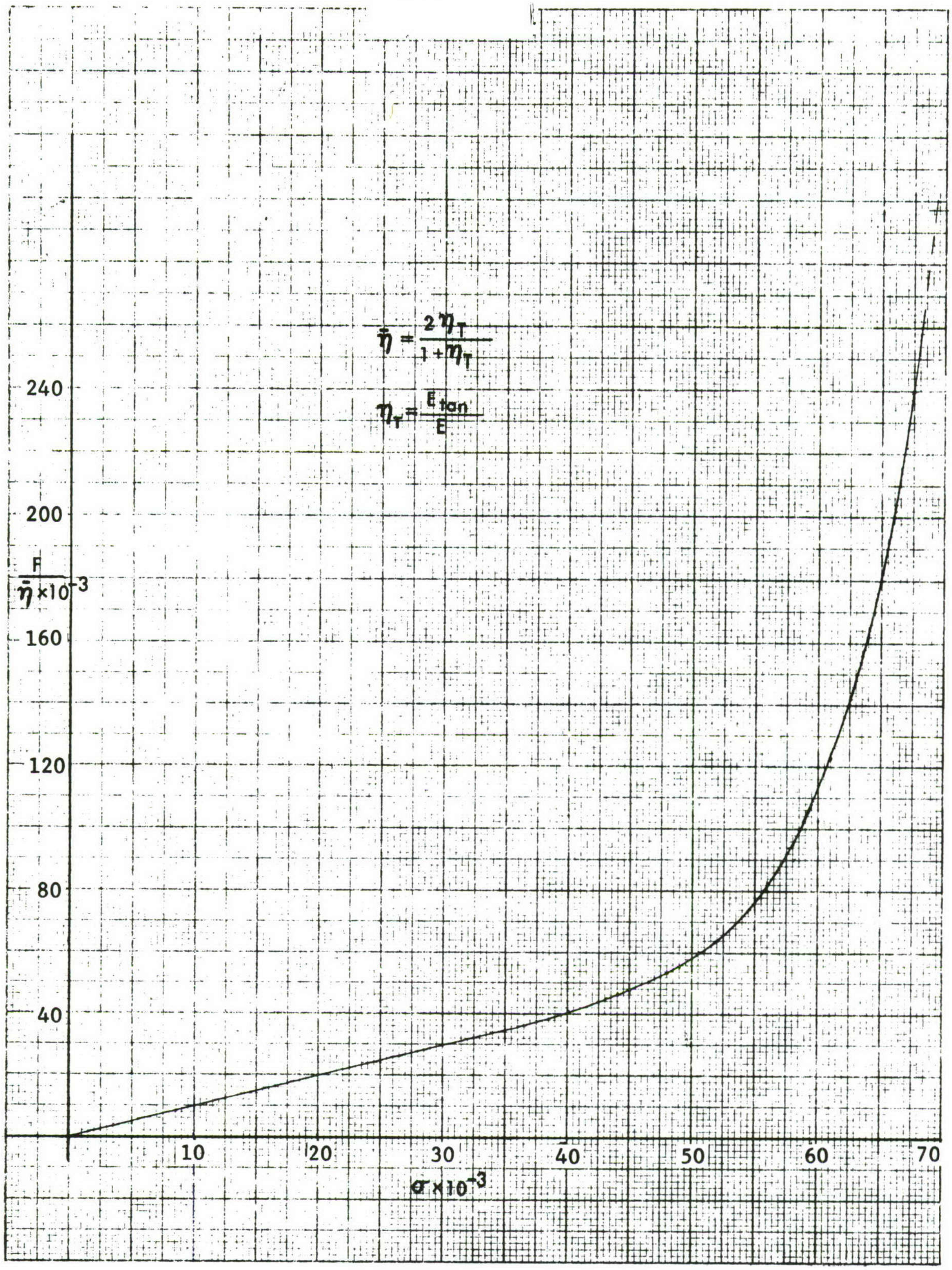


Figure 41 Crippling Stress Allowable Curve for 7050 - T76 Aluminum (With 8% Tempature Reduction)

To substantiate the lower surface stress levels, the maximum operating stress is compared with the allowable fatigue stress, the critical crack growth stress and the static tension strength of the material:

σ_{LWR} = 69500 psi = maximum applied ultimate stress in the lower surface (Reference Table V3-1)

$K_M = \frac{M_U}{M_O} = 1.89$ = ratio of ultimate bending moment to maximum operating bending moment.

$\sigma_O = \frac{\sigma_{LWR}}{K_M} = \frac{69500}{1.89} = \underline{37000}$ psi

= maximum operating stress.

Since there are no stress risers in the lower skins, K_T = 1.0 and:

σ_{all} = $\underline{40300}$ psi = maximum allowable fatigue stress (Reference Figure 42 .

There are no bolt holes in the lower surface, consequently, crack growth is based on specified initial surface cracks. Thus, for a 4000-hour, non-inspected, fail-safe structure:

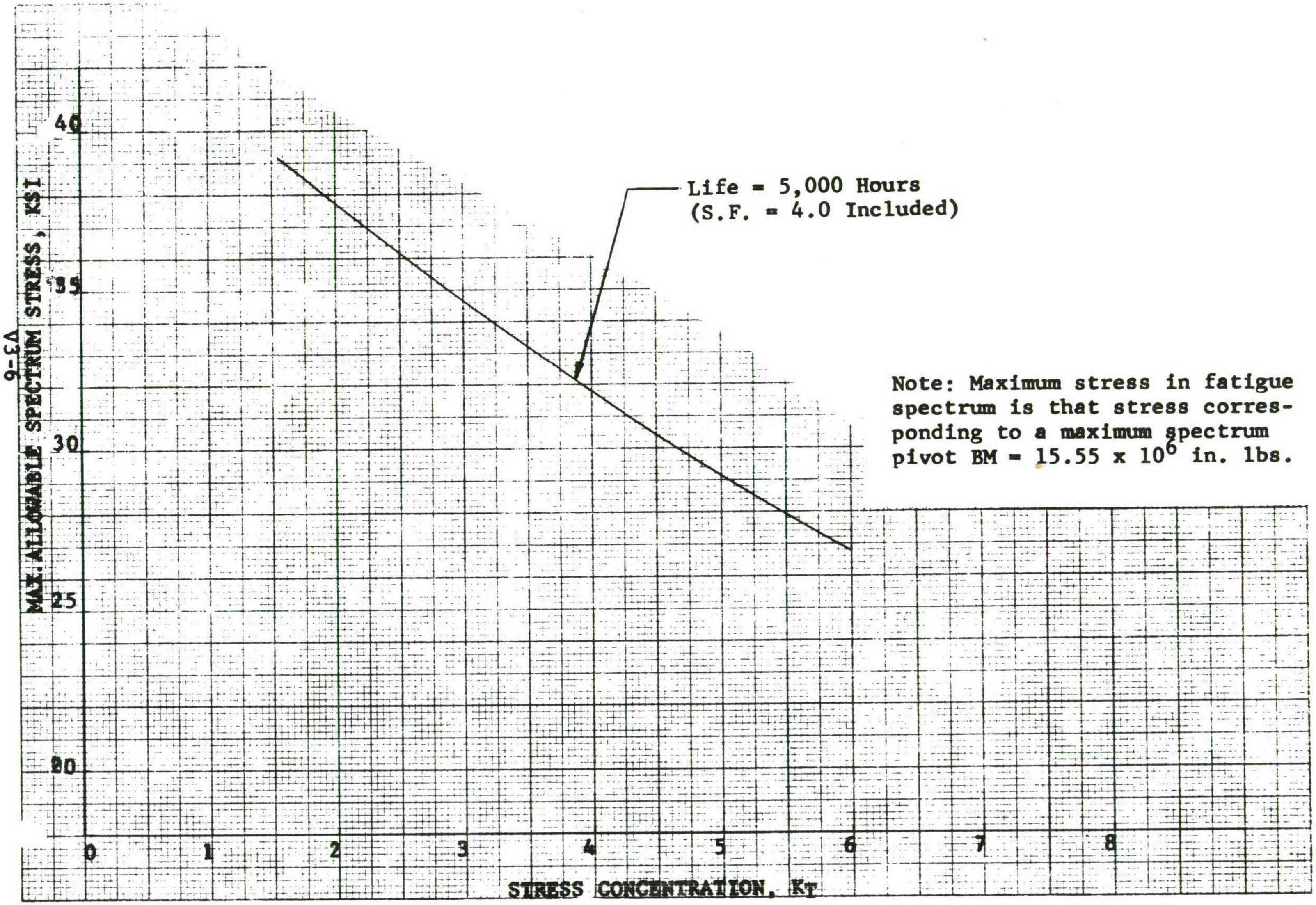
σ_{cg} = $\underline{45000}$ psi = critical crack growth stress for part-through crack in thick spar material (Reference Figure 43 .

σ_{cg} = $\underline{39500}$ psi = critical crack growth stress for through crack in thin laminates. (Reference Figure 44 .

$\sigma_s = \frac{F_{tu}}{1.89} = \frac{7000}{1.89} = \underline{37000}$ psi

= maximum allowable operating stress based on material static tension strength.

A comparison of the lower surface allowable stresses shows that the lower surface is sized by material static strength limitations.



Note: Maximum stress in fatigue spectrum is that stress corresponding to a maximum spectrum pivot BM = 15.55×10^6 in. lbs.

Figure 42

C.S.S. 140 Lower Surface
ADP Wing Preliminary Fatigue Design Allowable Curves
Based on Phase IA Tested S/N Data (3-in. Plate)
Applicable to X7050-T73651 PL Alloy

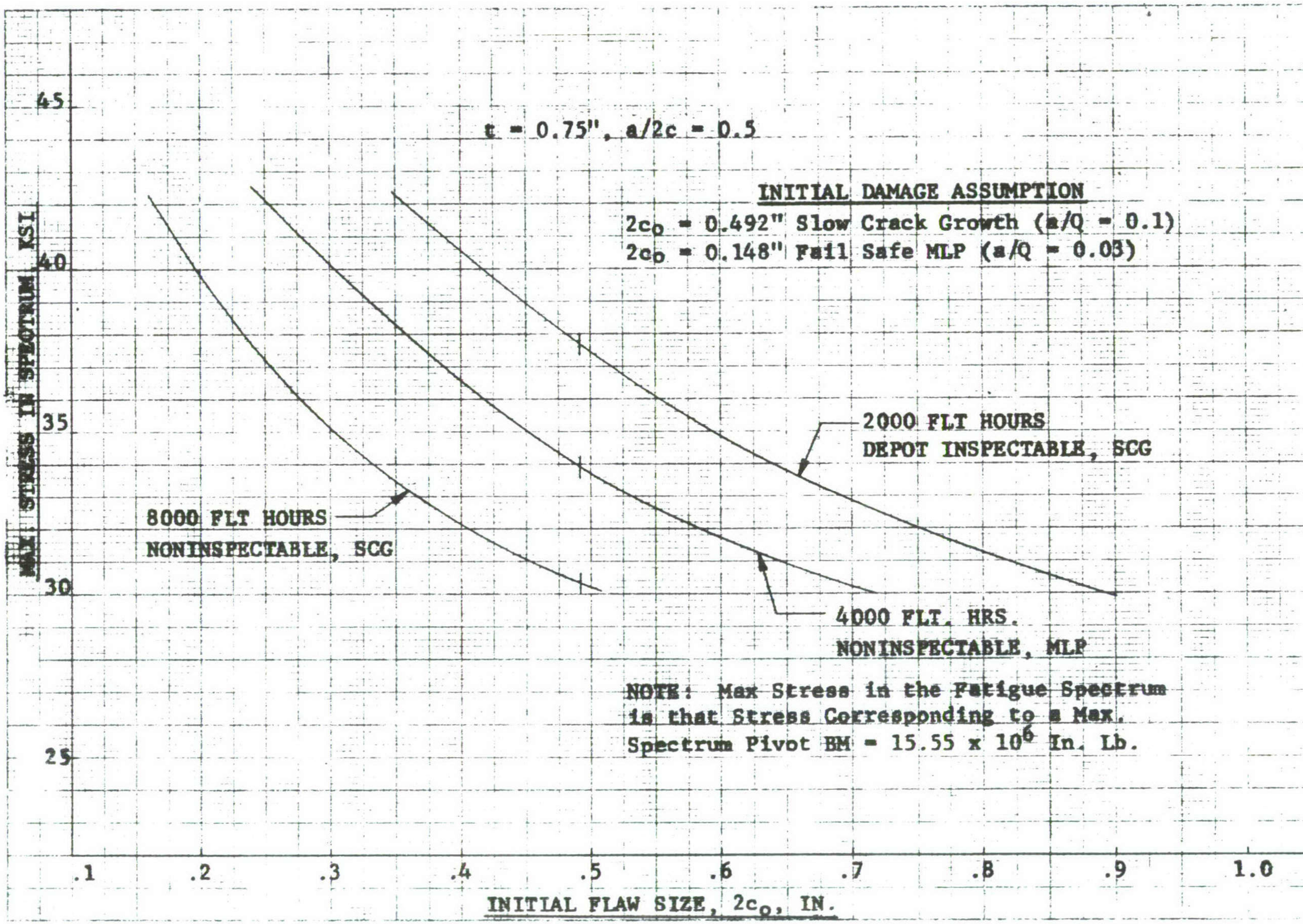


Figure 43 C.S.S. 140 Lower Surface 7050 Aluminum PL Alloy Part Through Surface Crack

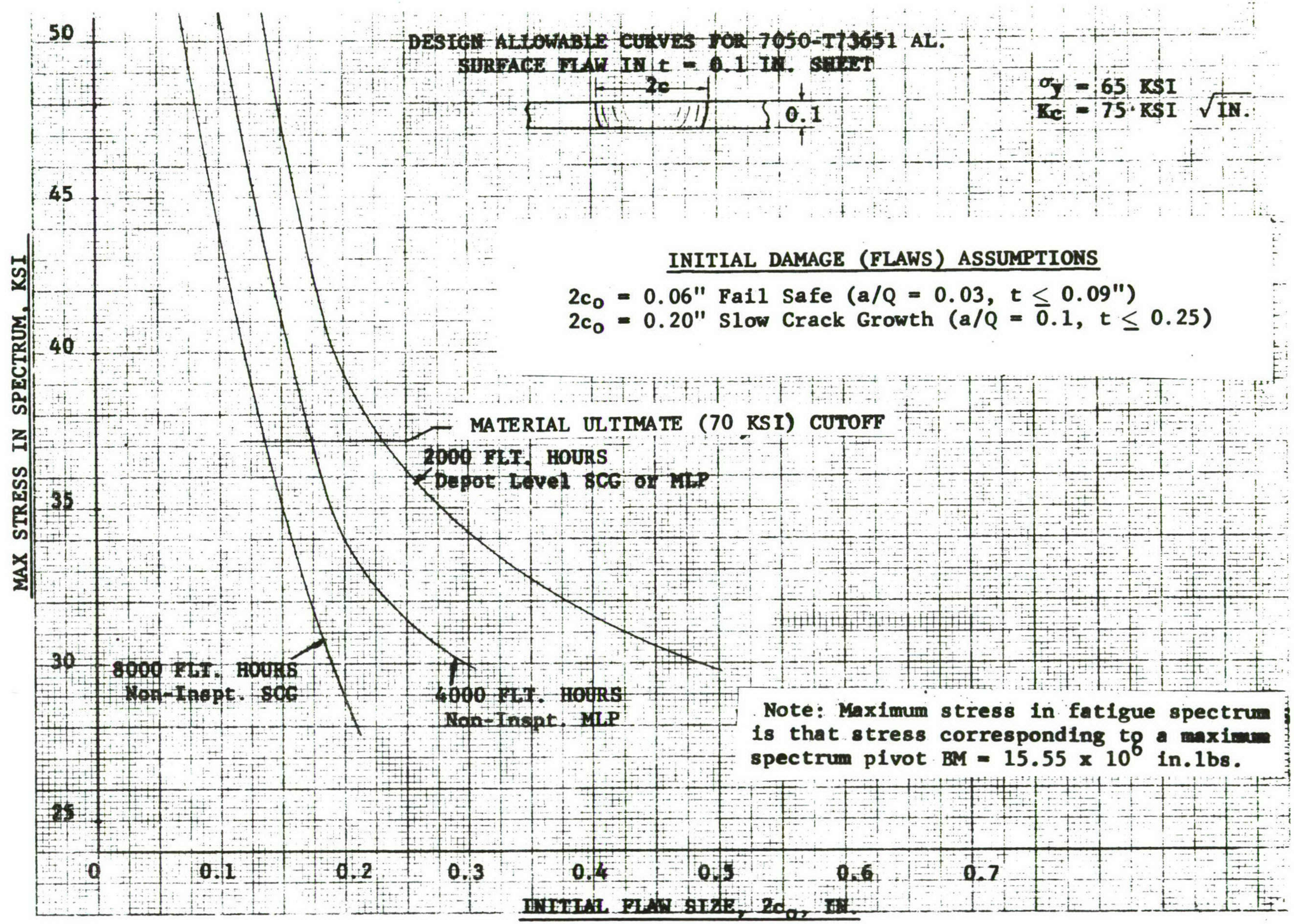


Figure 44 Design Allowable Curves for 7050-T73651 Aluminum Surface Flaw in t = 0.1 in. Sheet

From Table XXVI the total axial load carrying area required for Analytical Assembly No. 610RA003 is:

$$A_{LC} = 25.33 + 23.73 = 49.06 \text{ in}^2$$

The weight of the axial load carrying material required for the analytical assembly is:

$$W_{LC} = \rho A_{LC} L = (.101)(49.06)(48) = \underline{238} \text{ lbs.}$$

where: ρ = material density

L = length of analytical assembly

The final weight breakdown for Analytical Assembly 610RA003 is:

Bending material	=	238.00 lbs.
Shear webs	=	26.04 lbs.
Honeycomb Core	=	3.33 lbs.
Upper Panel Fasteners	=	6.51 lbs.
Adhesive	=	10.02 lbs.
TOTAL WEIGHT		283.90 LBS.

V.4 SAMPLE CALCULATIONS OF PRELIMINARY DESIGN WING

Cross-section required at CSS 107, outboard of splice, assuming no penalty for holes, in order to obtain a data point for skin thickness curve. Actual thickness must reflect lower allowables for holes needed to splice to the wing pivot test fixture.

Element(1)	f (ksi)	Nx (kips/in)	(w)	Px (kips)	t = Nx/f	A
1	44.0			45.20		1.03
2	49.0	34.77	(14.15)	492.00	.71	10.04
3	55.0			25.90		.47
4	56.5	41.16	(14.60)	601.00	.73	10.64
5	59.0			31.10		.53
6	56.0	30.64	(14.85)	455.00	.55	8.13
7	53.2			28.9		.54
8	46.8	7.24	(14.20)	103.00	.15	2.20
9	38.1			15.80		.41
10	46.2			16.50		.36
11	55.0	9.0	(14.20)	127.80	.16	2.32
12	61.6			29.00		.47
13	65.7	30.5	(14.85)	452.93	.46	6.89
14	69.5			22.00		.32
15	69.7	48.0	(14.60)	700.80	.69	10.05
16	70.0			17.50		.25
17	65.4	40.0	(14.15)	566.00	.61	8.65
18	60.4			36.00		.60

(1) See Figure 40 for location of elements.

Cross-section at CSS 140:

Element	K	f	h	A	M
1	.740	44.0	5.196	1.19	272
2	.830	49.0	6.061	6.79	2,020
3	.923	55.0	6.925	.95	362
4	.952	56.5	7.351	6.81	2,830
5	1.000	59.0	7.777	.56	258
6	.950	56.0	7.702	6.54	2,830
7	.900	53.2	7.627	.86	352
8	.789	46.8	7.264	3.51	1,195
9	.645	38.1	6.900	.87	228
10	.660	46.2	-3.436	.89	141
11	.785	55.0	-3.850	2.70	571
12	.879	61.6	-4.263	.56	147
13	.938	65.7	-4.446	3.15	1,650
14	.990	69.5	-4.628	.91	293
15	.994	69.7	-4.573	5.48	1,730
16	1.000	70.0	-4.417	.58	180
17	.931	65.4	-4.065	5.50	1,465
18	.861	60.4	-3.713	1.16	260
				23.43	16,784*

*v/s 16,625 in TR-4

Cross-section required at CSS 190 using Nx curves (F400A):

Element	f*	Nx	(w)	Px	t = Nx/f	A
1	44.0			33.9		.77
2	49.0	15.7	(11.8)	185.0	.35	
3	55.0			17.5		.32
4	56.5	20.6	(11.11)	229.0	.38	
5	59.0			17.2		.29
6	56.0	18.9	(11.61)	219.0	.35	
7	53.2			16.6		.31
8	46.8	16.1	(11.04)	178.0	.34	
9	38.1			28.5		.75
10	46.2			42.0		.91
11	55.0	14.0			.25	
12	61.6			23.5		.38
13	65.7	17.0			.26	
14	69.5			25.0		.36
15	69.7	21.0			.30	
16	70.0			21.0		.30
17	65.4	16.5			.25	
18	60.4			33.5		.55

*Distribution as at CSS 140

Ref: Analytical Assembly 610 RA 029

Obtain skin and cap areas at <u>CSS 270</u> using baseline loads (see 610 RW 001) for Cond. F400A.

ELEMENTS	1	2	3	4	5	6	7	8	9
σ_x	-20.2	-23.23	-75.70	-26.70	-28.9	-26.20	-28.4	-23.5	-25.1
t	-	.300	-	.285	-	.285	-	.230	-
A	.8		.42		.431		.440		.815
Nx		-6.98		-7.61		-7.47		-5.41	
Px	-16.16	-59.33	-10.79	-64.69	-12.46	-63.50	-12.50	-45.99	-20.46
		8.5		8.5		9.0		8.6	

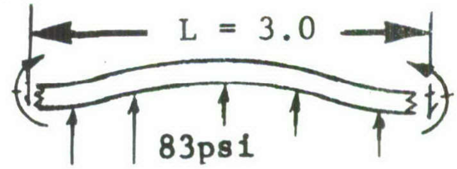
ELEMENTS	18	17	16	15	14	13	12	11	10
σ_x	32.0	34.35	35.8	36.00	38.1	34.75	35.9	29.65	30.2
t	-	.188	-	.188	-	.170	-	.165	-
A	.90		.42	1.598	.415		.370	1.42	.725
Nx		6.46		6.77		.591		4.89	
Px	28.8	54.91	15.04	57.53	15.81	53.17	13.28	42.07	21.90

At CSS 270:

Element	K	f	$(P)_{RQD}$	$(A)_{RQD}$	WIDTH	t	t_{CR}
1	.699	-41.24	-16.16	.392			
2	.804	-47.44	-59.33	1.251	8.5		.161
3	.889	-53.04	-10.79	.203			
4	.924	-54.52	-64.69	1.187	8.5		.166
5	1.000	-59.00	-12.46	.211			
6	.907	-53.51	-63.50	1.187	9.0		.170
7	.983	-58.00	-12.50	.216			
8	.813	-47.97	-45.99	.959	8.6		.149
9	.869	-51.27	-20.46	.399			
10	.793	55.51	21.90	.395			
11	.778	54.46	42.07	.772	8.6	.090	
12	.942	65.94	13.28	.201			
13	.912	63.84	53.17	.833	9.0	.098	
14	1.000	70.0	15.81	.226			
15	.945	66.15	57.53	.870	8.5	.102	
16	.940	65.80	15.04	.229			
17	.902	63.14	54.91	.870	8.5	.102	
18	.840	58.80	28.8	.490			
				10.941			

Sizing at CSS 340 will be based on minimum gages for manufacture, since 83 psi fuel pressure loadings in 3.00 (fixed ended bays) maximum width inside spar caps requires:

$$t = \sqrt{\frac{6M}{7(10^4)}} = \sqrt{\frac{6(83)9}{12(7)10^4}} = .073 \text{ , M}$$



Maximum spar spacing at CSS 270 is 9.0 in., between CS and AAS. Unsupported plate width = 9.0 - 2.5 = 6.5.

$$F_c = \frac{6.0(10^7)(t_6^2)}{(6.5)^2} = \frac{7.06}{t_6}(10^3), \quad \frac{CE(t_6^2)}{b^2} = \frac{N_x}{t_6}$$

$$C = 6$$

$$t_6^3 = \frac{7.06(6.5)^2}{6.0(10^4)}, \quad (t_6)_{RQD} = .170 \text{ in.}$$

$$(t_4)_{RQD} = \sqrt[3]{\frac{7.63(6.0)^2}{(6.0)10^4}} = .166 \text{ in.}$$

$$(t_2) = \sqrt[3]{\frac{6.97(6.0)^2}{(6.0)10^4}} = .161 \text{ in.}$$

$$(t_8)_{RQD} = \sqrt[3]{\frac{5.37(6.1)^2}{(6.0)10^4}} = .149 \text{ in.}$$

Wall thickness for pivot pylon fitting:

$$f_b = 70(10^3) = \frac{2.02(10^6)(4.25)}{(\frac{8.25}{2})^3 t} = t = .556$$

Upper skin thicknesses at <u>CSS 233</u>:

BAY 2 $t = .200$ in.

x 4 $t = .225$ in.

x 6 $t = .240$ in.

x 8 $t = .200$ in.

Find thickness of upper plates at <u>CSS 233</u>:

$$t^3_{RQD} = \frac{(Nx)b^2}{63(10^6)}$$

$$(t_6{}^3)_{RQD} = \frac{14(7.9)^2}{63(10^3)}, \quad (t_6)_{RQD} = .240$$

$$(t_8{}^3)_{RQD} = \frac{9.5(7.3)^2}{63(10^3)}, \quad (t_8)_{RQD} = .200$$

$$(t_4{}^3)_{RQD} = \frac{13.5(7.3)^2}{63(10^3)}, \quad (t_4)_{RQD} = .225$$

$$(t_2{}^3)_{RQD} = \frac{9.5(7.3)^2}{63(10^3)}, \quad (t_2)_{RQD} = .200$$

Find thickness of upper plates at <u>CSS 190</u> for buckle resistance at ultimate load:

$$F_c = \frac{6.0(10.5)10^6 t^2}{b^2} = \frac{Nx}{t}$$

$$t^3_{RQD} = \frac{(Nx)b^2}{63(10^6)}$$

$$(t_2)^3_{RQD} = \frac{15.7(8.8)^2}{63(10^3)}, \quad (t_2)_{RQD} = .268$$

Upper skin required in BAY 2 , FS to FAS:

CSS	BAY WIDTH	b = WIDTH, BOLT TO BOLT	NX2 UPPR X 10^{-3} LBS PER INCH	$t_{CR} = \left[\frac{NX2\ (b^2)}{6.98(10.5)10^6}\right]^{1/3}$	t_{FINAL}
107	14.0	11.8	35.5	.568*	.879
118	13.5	11.3	31.0	.496*	.730
120					
140	13.1	10.9	27.0	.432*	.518
160					
180					
193	11.3	9.1	16.4	.265	.350
200					
210	10.7	8.5	13.0	.234	.295
220					
233	9.8	7.6	9.4	.195	.200
240					
250	9.2	7.0	8.5	.178	.195
260					
268	8.6	6.4	6.5	.154	.161
280					
292	7.7	5.5	3.5	.113	.125
300					
340	6.0	3.8	.75	.053	.067

*Limited by F_{CY} = 62.5 ksi

Upper skin required in BAY 4 , FAS to CS:

CSS	BAY WIDTH	b = WIDTH, BOLT TO BOLT	NX4 UPPR X 10^{-3} LBS PER INCH	$t_{CR} = \left[\frac{NX4\ (b^2)}{6.98(10.5)10^6}\right]^{1/3}$
107	14.5	12.3	41.5	.664*
118	14.2	12.0	33.5	.536*
120				
140	13.1	10.9	29.5	.472*
160				
180				
193	11.2	9.0	21.0	.336*
200				
210	10.6	8.4	17.5	.280*
220				
233	9.8	7.6	13.5	.220
240				
250	9.2	7.0	11.0	.194
260				
268	8.6	6.4	7.5	.161
280				
292	7.7	5.5	5.5	.131
300				
340	6.0	3.8	1.0	.058

*Limited by F_{CY} = 62.5 ksi

Upper skin thickness required for stability in BAY 6 , between CS and AAS:

CSS	BAY WIDTH	b = WIDTH, BOLT-BOLT	NX6 UPPR X 10^{-3} LBS PER INCH	$t_{CR} = \left[\frac{NX6\ (b^2)}{6.98(10.5)10^6}\right]^{1/3}$
107	14.8	12.6		
118	14.4	12.2	32.0	.512*
120				
140	13.6	11.4	27.0	.432*
160				
180				
193	11.9	9.7	18.5	.296*
200				
210	11.2	9.0	16.5	.263
220				
233	10.4	8.2	14.0	.234
240				
250	9.7	7.5	12.5	.209
260				
268	9.0	6.8	7.5	.168
280				
292	8.1	5.9	6.0	.142
300				
340	6.2	4.0	-	

*Limited by F_{CY} = 62.5 ksi

Lower skin thickness in BAY 2 :

CSS	WIDTH	b	$.5NX_{2LWR}$	$t_{CR} = \left[\frac{35\ b^2}{6.98(10^4)}\right]^{1/2}$	$\frac{.5NX_{4LWR}}{35000}$	t_{FINAL} (IN)	$\frac{NX2_{LWR}}{t_{FINAL}}$ (KSI)
107	14.0	10.9	17.50	.244	.500		
118	13.5	10.4	16.75	.233	.479		
120							
140	13.1	10.0	13.75	.224	.393	.410	67.07
160							
180							
193	11.3	8.2	8.25	.184	.236	.252	65.48
200							
210	10.7	7.6	6.75	.170	.193		
220							
233	9.8	6.7	5.50	.150	.157	.180	61.11
240							
250	9.2	6.1	4.50	.137	.129		
260							
268	8.6	5.5	3.75	.123	.107	.180	41.67
280							
292	7.7	4.6	2.75	.103	.079		
300							
340	6.0	2.9	.80	.065	.023		

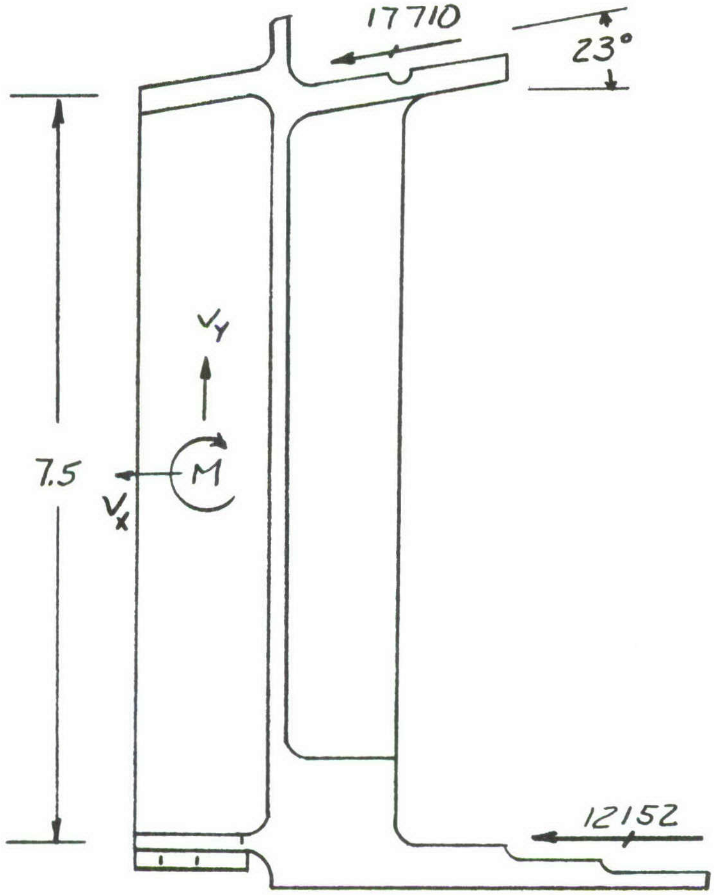
Lower skin thickness in BAY 4 :

CSS	WIDTH	b	$.5NX_{4LWR}$	$t_{CR} = \left[\frac{35\ b^2}{6.98(10^4)}\right]^{1/2}$	$\frac{.5NX_{4LWR}}{35000}$	t_{FINAL}	$\frac{NX4_{LWR}}{t_{FINAL}}$ (KSI)
107	14.5	11.3	23.75	.253	.679		
118	14.2	11.0	22.50	.246	.643	.645	69.77
120							
140	13.1	9.9	14.50	.222	.414	.410	70.73
160							
180							
193	11.2	8.0	10.50	.179	.300	.300	70.00
200							
210	10.6	7.4	8.25	.166	.236	.250	66.0
220							
233	9.8	6.6	6.50	.148	.186		
240							
250	9.2	6.0	5.50	.134	.157	.186	59.14
260							
268	8.6	5.4	4.25	.121	.121	.170	50.00
280							
292	7.7	4.5	3.75	.100	.093	.150	43.33
300							
340	6.0	2.8	1.00	.063	.029	.100	

Lower skin thickness in BAY 6 :

CSS	BAY WIDTH	b	$.5NX_{6LWR}$ $\times 10^{-3}$ IN-LBS PER INCH	$t_{CR} = \left[\dfrac{35\ b^2}{6.98(10^4)}\right]^{1/2}$	$\dfrac{.5NX_{6LWR}}{35000}$
107	14.8	11.6	13.75	.259	.393
118	14.4	11.2	13.20	.251	.377
120					
140	13.6	10.4	13.50	.233	.386
160					
180					
193	11.9	8.7	8.50	.195	.243
200					
210	11.2	8.0	6.75	.179	.193
220					
233	10.4	7.2	6.00	.161	.171
240					
250	9.7	6.5	5.75	.146	.164
260					
268	9.0	5.8	3.50	.130	.100
280					
292	8.1	4.9	2.00	.110	.057
300					
340	6.2	3.0	1.00	.070	.029

SLAT ATTACHMENT



M = 78500 in-lbs (ult)
V_Y = 3290 lbs (ult)
V_X = 3370 lbs (ult)

$$\frac{78500}{7.5} = 10467 \text{ lbs (ult)}$$

$$\frac{3290}{\text{TAN}23°} = 7402$$

$$\frac{3370}{2} = 1685$$

$$\frac{10467 + 7402 - 1685}{\text{COS } 23°}$$

$$= 17710 \text{ lbs}$$

10,467 + 1685

= 12152 lbs

The reactions (17710 at upper surface and 12152 at lower surface) are provided along 6 inches, spanwise, using four 1/4 inch fasteners (19000 lbs capacity).

Find thickness at first row of bolts in pivot FTG splice.

$K_T = 3.4$, TL = 7050-T73651

$$(F_t)_{FATIGUE} = 33.0\left(\frac{29.3}{15.5}\right) = 62.38 \text{ ksi}$$

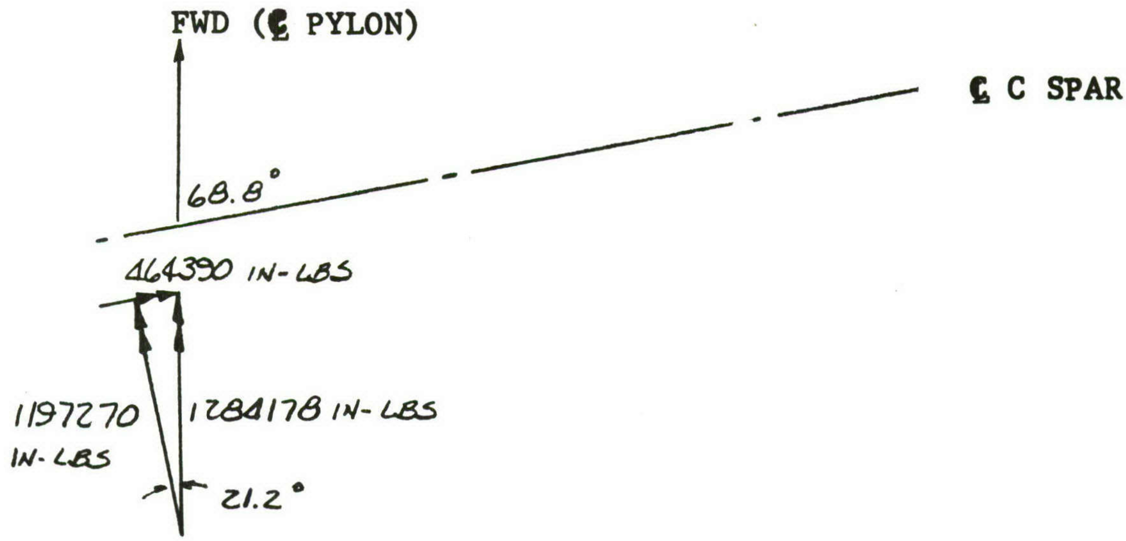
$$(F_t)_{F.S. + BOLT} = 30.2\left(\frac{29.3}{15.5}\right) = 57.09$$

$$(F_t)_{STATIC} = 70.00 \text{ ksi}$$

Using existing 5/8 bolts at 2.40 spacing,

$$t = \left(\frac{47000}{57090}\right)\left(\frac{2.400}{2.400-.625}\right) = 1.113 \text{ in.}$$

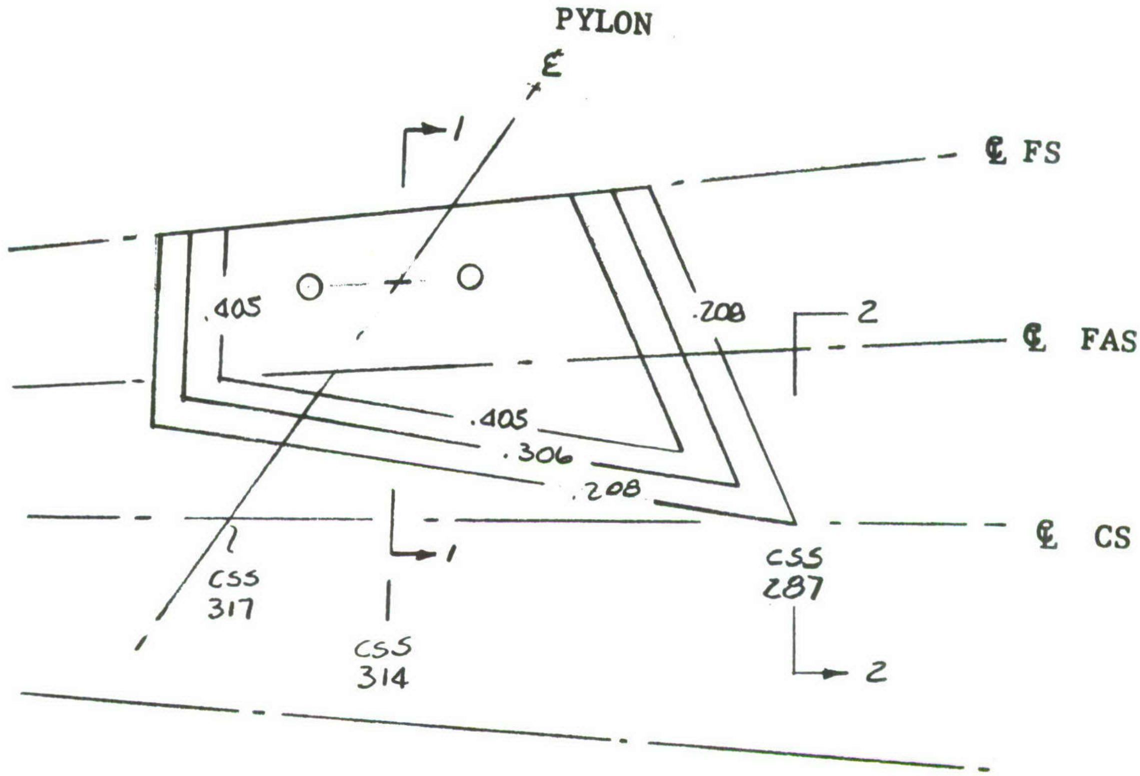
OUTBOARD FIXED PYLON



Obtain skin thickness between F.S. and F.A.S. required to introduce 1197270 in-lbs (normal to C.S.) and 464390 in-lbs torsion (in box between F.S. and F.A.A.).

$$\frac{1197270}{(6.50)6.50(70)10^3} = t_{RQD} = .405 \text{ in. (at section 1-1, next page)}$$

$$\frac{1197270}{7.5(32.00)70(10^3)} = t_{RQD} = .071 \text{ in. (at section 2-2)}$$



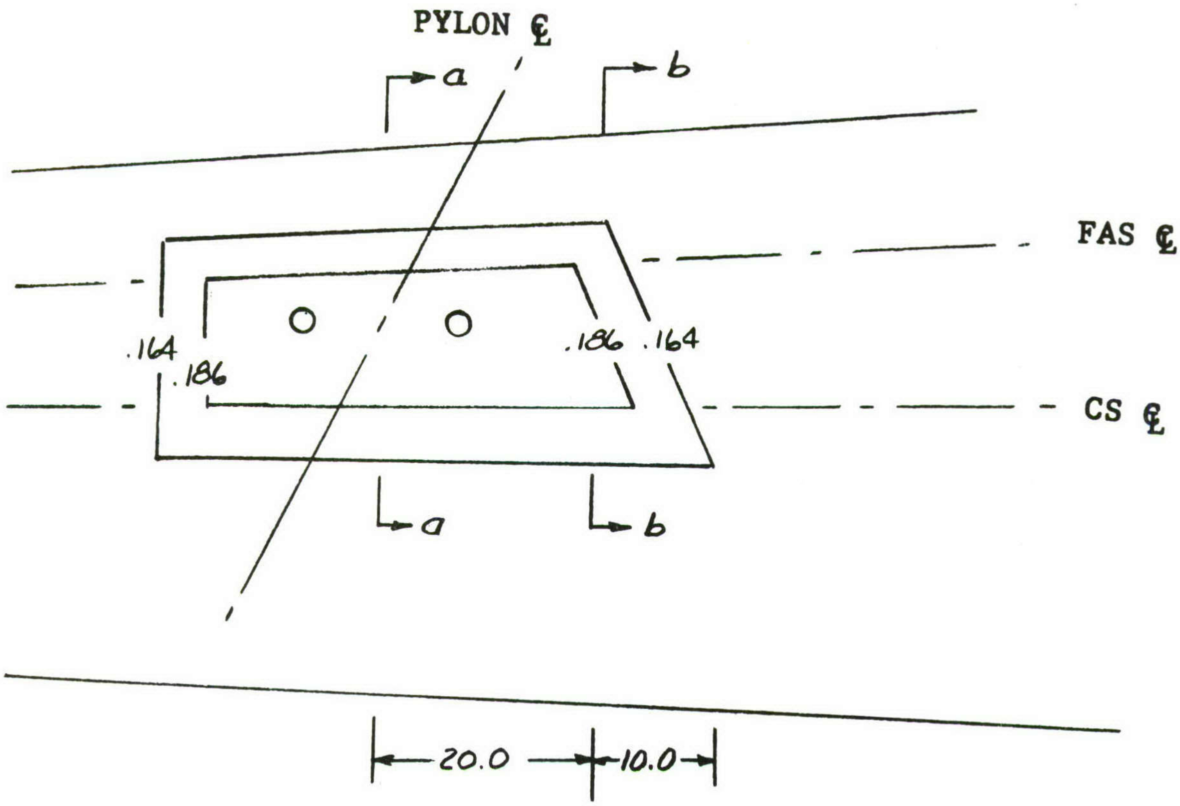
Fixed pylon fwd bolt attachment:

.3125 bolts $F_S = 150$ ksi, $P_S = 12.27$ K each

Flange Load $= \dfrac{1197270}{6.5} = 184195$ lbs.

$\dfrac{184195}{12.27} = 15$

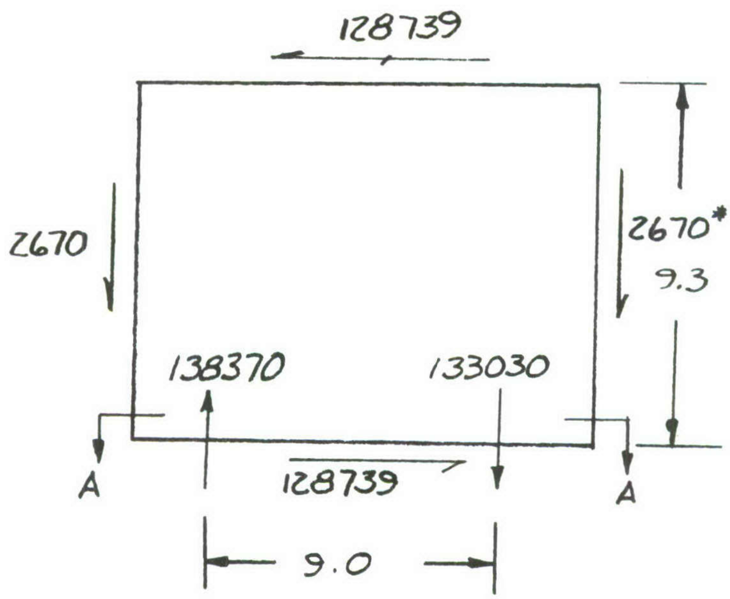
Inboard fixed pylon:



Obtain skin thickness between FAS and CS required to introduce 1,254,560 (COS 21.2°) = 1169656 in-lbs (all pitching in pylon plane is taken as a couple between the two fwd bolts and the aft hook with a 30 in. couple arm).

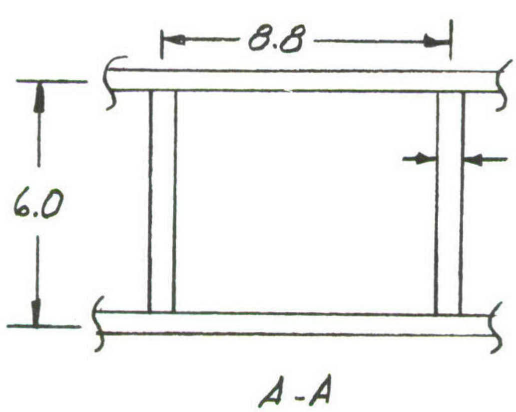
$$\frac{1169656}{9.0(10.0)70(10^3)} = t_{RQD} = .186 \text{ in. (at section a-a)}$$

Fixed pylon attachment:



*Check also for -41685/2 lbs (with negligible M_x). ~ OK

Section A-A must have bolt receptacles for 138370 lbs and must be capable of resisting 1,197,270 in-lbs.



$$t = \frac{133030\,(9.0)}{8.8(6.0)60(10^3)} = .378$$

V.5 STIFFNESS REQUIREMENTS

The baseline F-111F wing flutter and vibration margins have been established for existing hardware. The margins exceed 50% for the clean wing.

The flutter margins for the wing and stores combinations are estimated in many cases from the analysis of the F-111A. In these cases the margin for the F-111F was considered to exceed the F-111A margin due to the greater stiffness of the F-111F and carry-through structure.

Table XXVII lists the stiffness margins estimated for the F-111F for all of its store carriage combinations. The store combinations are defined in Table XXVIII.

To obtain these margins it has been assumed that for a reasonable uniform change the stiffness (k) is a function of the frequency squared (w^2). Also, that flutter speed (V) is proportional to frequency. Then, V is proportional to $\sqrt{K}$. The stiffness reduction percentage quoted in Table XXVII, is the amount which could be applied to K and still retain an adequate flutter speed to clear the configuration at its present operational level from an analysis standpoint.

This is an obvious oversimplification but it has value in preliminary design and trend evaluations. Specific changes from the F-111 when they are designed in detail, merit a flutter analysis to more adequately consider the problem variables. At that time it may be possible to achieve adequate flutter margins for store carriage by adjusting mass and stiffness rather than by simply increasing stiffness.

Table XXVII

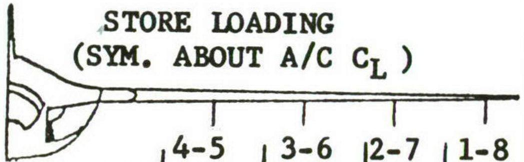
ESTIMATED STIFFNESS MARGINS ON F-111F WING

Loadings from Table XXVIII Group Number	Estimated Stiffness Red. Available (%)	Remarks
1-6	42	
7-9	20	F-111F Analysis @ 50° and 26° indicates better margin probable
10-12	26	Flight test was required to clear this configuration originally on F-111A
13-15	31	
16-17	50	Flight test has problems with carriage and release of this configuration
18-19	27	
20-23	50	See Note 1
24-27	42	
28-30	50	See Note 1
31-31B	42	
32-33	49	
34	45	
35	39	
36	36	
37	43	
38-39	50	
40-45	43	
46-48	50	
49	36	
50-51	47	
52-53	50	See Note 1
54-57	42	
58-60	50	See Note 1
61	45	
62	47	
63-66	44	
67	50	
68-70	45	
71-72	50	See Note 1
73	21	
74-79	23	
Clean Airplane	50	

Note 1: Operating limits should be based on flight test results since flight control problems were encountered during original flight testing.

Table XXVIII

F-111A EXTERNAL STORES LOADING



NUMBER	STORE LOADING (SYM. ABOUT A/C C_L)	4-5	3-6	2-7	1-8	WING SWEEP	OPERATIONAL LIMITS	REMARKS
1	AIM-9B	1	2			16-35	Clean A/P	
2	AIM-9B	1	P			36-49	Clean A/P or, along 1.0M @ S.L. to 1.78M @ 40K, to clean A/P.	
3	AIM-9B	P	2					
4	AIM-9B &		2			50-72.5	Along 1.0M @ S.L. to 1.78M @ 40K, 1.78M 40K.	
	B-43	1						
5	AIM-9B &		2					
	B-61	1						
6	AIM-9B &		2					
	B-57	1						
7	B-43	1	1			16-72.5	Clean A/P.	
8	B-43	1						
9	B-43		1					
10	B-61	1	1					
11	B-61	1						
12	B-61		1					
13	B-57	1	1					
14	B-57	1						
15	B-57		1					

Table XXVIII (Contd)

F-111A EXTERNAL STORES LOADING

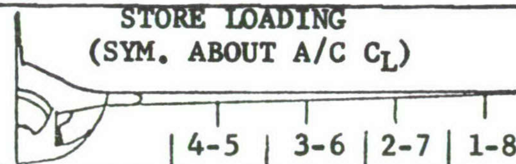
NUMBER	STORE LOADING (SYM. ABOUT A/C C_L) 	4-5	3-6	2-7	1-8	WING SWEEP	OPERATIONAL LIMITS	REMARKS
16	BLU-1C/B	2	2	2		16-26	Clean A/P to .9M	Weapon Lim.
	(With or W/O	2	2	P				
	Fins)	2	P	P				
17	BLU-27/B	2	2	2				
	(With or W/O	2	2	P				
	Fins)	2	P	P				
18	BLU-1C/B	2	2			16-44	Clean A/P to .9M	Weapon Lim,
	(Finned)	2	P			45-54		
19	BLU-27/B	2	2					
	(Finned)	2	P					
20	CBU-24	6	6			16-25	Clean A/P to .7M	
21	CBU-29	6	6			26-44	460 KCAS to .8M	Flutter Lim.
22	CBU-49	6	6			45-54	.8M	
23	CBU-52	6	6					
24	CBU-24		6			16-25	Clean A/P to .7M	
25	CBU-29		6			26-44	Clean A/P to .9M*	
26	CBU-49		6			45-72.5	.9M*	
27	CBU-52		6				*Except 36-71°, .9M @ 24K	
							to .8M 30K	
28	CBU-24	4	4			16-25	.6M	
29	CBU-29	4	4			26-44	460 KCAS to .8M	Flutter Lim.
30	CBU-49	4	4			45-54	.8M	
31	CBU-24		4			16-25	.6M	
31A	CBU-29		4			26-72.5	.8M	
31B	CBU-49		4					

Table XXVIII (Contd)

F-111A EXTERNAL STORES LOADING

NUMBER	STORE LOADING (SYM. ABOUT A/C ℄)	4-5	3-6	2-7	1-8	WING SWEEP	OPERATIONAL LIMITS	REMARKS
32	CBU-30/A	1	1	1		16-26	Clean A/P to .9M	Weapon Lim.
	CBU-30/A	1	1	P				
	CBU-30/A	1	P	P				
33	CBU-30/A	1	1			16-44	Clean A/P to .9M	Weapon Lim.
	CBU-30/A	1	P			45-72.5	.9M	
34	LAU-3/A	3	3	3	3	16	Clean A/P to .9M	
	LAU-3/A	3	3	3	P	17-26	400 KCAS to Clean A/P to .9M	
	LAU-3/A	3	3	P	P			
	LAU-3/A	3	P	P	P			
35	MK-20-Mod. 2	6	6			16-25	Clean A/P to .7M	
	MK-20-Mod. 2	6	P			26-44	Clean A/P to .9M	
						45-54	. 9M	
36	MK-20-Mod. 2		6			16-25	Clean A/P to .7M	
						26-44	Clean A/P to .9M*	
						45-72.5	.9M*	
							*Except 36-71°, .9M @ 24K to .8M 30K	
37	MK-36		6			16.25	Clean A/P to .7M	.9M Weapon Limit
						26.44	Clean A/P to .9M*	
						45-72.5	.9M*	
							* Except 36-71°, .9M @ 24K to .8M 30K	
38	MK-36	4	6			16-25	.6M	
	MK-36	4	P			26-44	.7M	
39	MK-36	4	4			45-54	.8M	

Table XXVIII (Contd)

F-111A EXTERNAL STORES LOADING

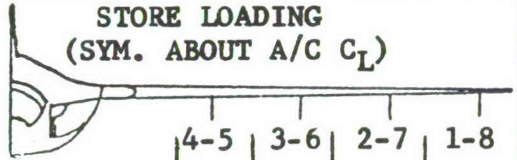
NUMBER	STORE LOADING (SYM. ABOUT A/C C_L) 	4-5	3-6	2-7	1-8	WING SWEEP	OPERATIONAL LIMITS	REMARKS
40	MK-82 or 82S	6	6			16-25	Clean A/P to .7M	
	MK-82 or 82S	6	P			26-44	Clean A/P to .9M	
41	MK-82	6				45-54	.9M	
42	MK-82 or 82S	4	6			16-25	.6M	.9M Weapon Limit on 82S
43	MK-82 or 82S	4	4			26-44	.7M	
44	MK-82S		4			45-54	.8M	
45	MK-82 or 82S		6			16=25	Clean A/P to .7M	
						26-44	Clean A/P to .9M*	
						45-72.5	.9M*	
							*Except 36-71°,.9M @ 24K to .8M 30K	
46	MK-84	1	1			16-35	Clean A/P	
		1	P			36-49	Clean A/P	Weapon Limit
47	MK-84	1				50-72.5	650 KCAS to 1.3M	Weapon Limit
48	MK-84		1					
49	M-117A1	3	3	3	3	16-26	Clean A/P to .9M	
50	M-117A1 or R	3	3			16-44	Clean A/P to .9M	
						45-54	.9M	
51	M-117A1	3						
52	M-117A1 or R	6	6			16	Clean A/P to .7M	
	M-117A1-or R	6	P			26-44	460 KCAS to .8M	Flutter Lim.
53	M-117A1	6				45-54	.8M	
54	M-117A1		6			16	Clean A/P	
						26-44	Clean A/P to .9M*	
						45-72	.9M*	
							* Except 36-71°, .9M @ 24K to .8M 30K	

Table XXVIII (Contd)

F-111 EXTERNAL STORES LOADING

NUMBER	STORE LOADING (SYM. ABOUT A/C C_L)	4-5	3-6	2-7	1-8	WING SWEEP	OPERATIONAL LIMITS	REMARKS
55	M-117R or D		6			16	Clean A/P to .7M	
56	M-1117R		5			26-72.5	.8M	
57	M-117R		1					
58	M-117A1	4	6			16	.6M	
59	M-117A1 or R	4	4			26-44°	460 KCAS to .8M	Flutter Lim.
	M-117A1 or R	4	P			45-54	.8M	
60	M-117A1 or R		4			16-25	.6M	
						26-72.5	.8M	
61	M-118	1	1			16	Clean A/P to .7M	.9M Weapon Limits
	M-118	1	P			26	Clean A/P to .9M	
						27-44	530 KCAS to Clean A/P to .9M	
						45-54	530 KCAS to .9M	
62	M-118		1			16	Clean A/P to .7M	
						26-44	Clean A/P to .9M*	
						45-72.5	.9M*	
							*Except 36-71°, .9M @ 20K to .85M 25K	
63	SUU-20A/A	1				16-35	Clean A/P	
64	SUU-20A/A		1			35-49	Clean A/P	Weapon Lim.
65	SUU-20A/A	1 on 4 only				50-72.5	650 KCAS to 1.3M	Weapon Lim.
66	SUU-20A/A		1 on 3 only					
67	TDU-10B with A/A 37U-15		1 on 3 only			16-25	250 KCAS to .55M	
						26	350 KCAS to .8M (Captive Flt.)	Store Lim.
							475 KCAS to .8M (In Tow)	Store Lim.

Table XXVIII (Contd)

F-111A EXTERNAL STORES LOADING

NUMBER	STORE LOADING (SYM. ABOUT A/C C_L)	4-5	3-6	2-7	1-8	WING SWEEP	OPERATIONAL LIMITS	REMARKS
68	TDU-11/B	1				16-26	Clean A/P	
69	TDU-11/B	1 (on 4 only)				27-49	Along .8M at S.L. to 1.6M @ 40K, to Clean A/P or 1.11 M	
70	TDU-11/B & AIM-9B	1/ /1	1/ /1			50-72.5	Along .8M at S.L. to 1.64M @ 40K	TDU on L. Wing AIM on R. Wing
71	600 Gal.Tank	1	1			16-25	.5M	.9M Tank Lim
		1	P			26-49	.6M to 370 KCAS to .9M	
72	600 Gal. Tank	1				50-62	.9M	
73	600 Gal. Tank		1			16-25	.45M	
						26-54	.8M	
74	600 Gal. Tank		1			16-25	.5M	
	& B-43	1				26-44	400 KCAS to .75M to 350 KCAS to .9M	
75	600 Gal. Tank		1			45-49	460 KCAS to .8M to 390 KCAS to .9M	
	& B-61	1						
						50-72.5	.85M to 510 KCAS to .9M	
76	600 Gal Tank		1					
	& B-57	1						
77	600 Gal. Tank		1			16-25	.45M	
	& B-43	1(4 or 5 only)				26-44	.400 KCAS to .75M to 350 KCAS to .8M	
78	600 Gal. Tank		1			45-49	460 KCAS to .8M	
	& B-61	1(4 or 5 only)				50-54	.8M	
79	600 Gal. Tank		1					
	& B-57	1(4 or 5 only)						

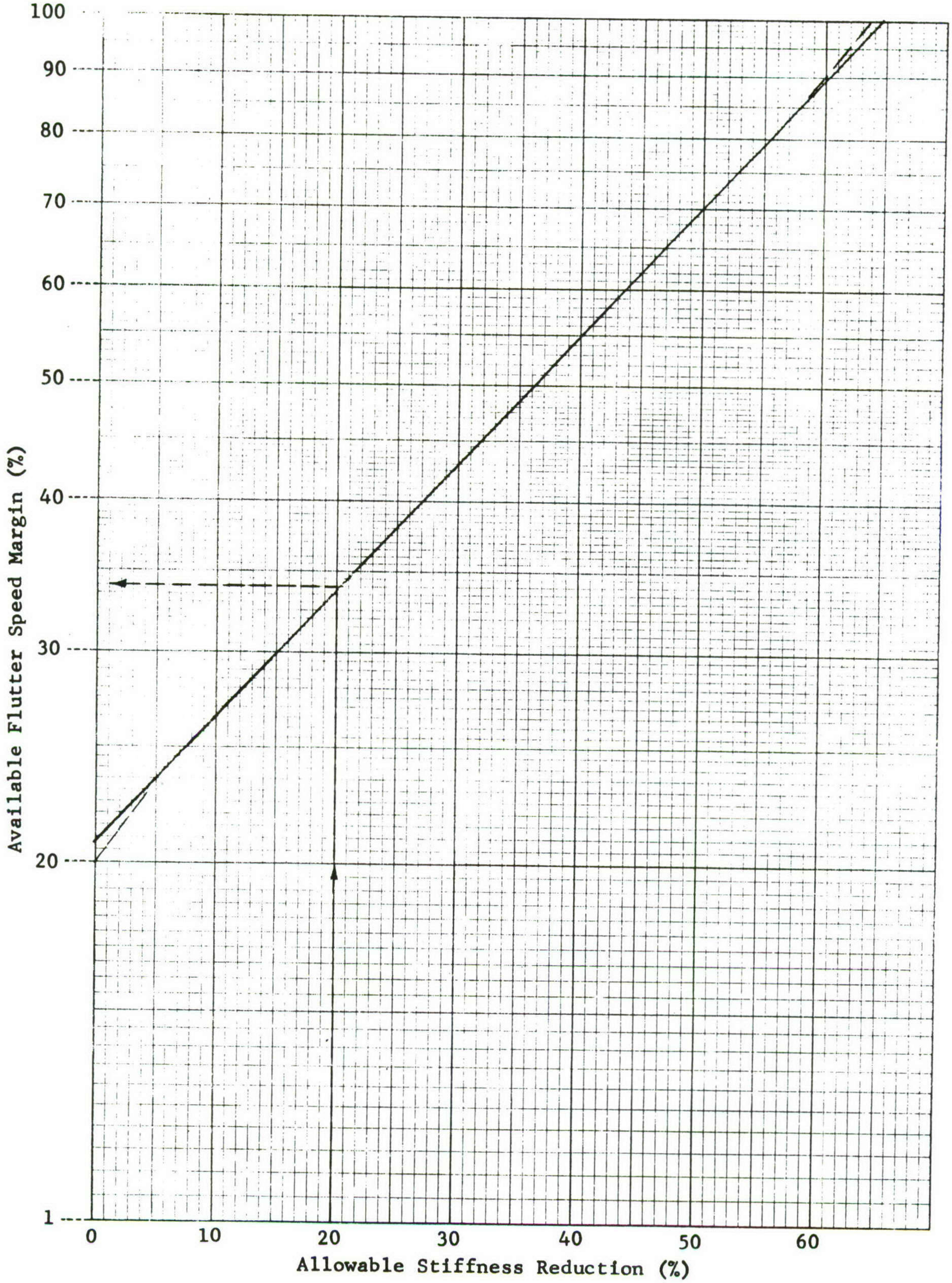


Figure 45 Allowable Wing Stiffness Reduction
vs % Flutter Speed Margin
(Minimum Margin 20%)

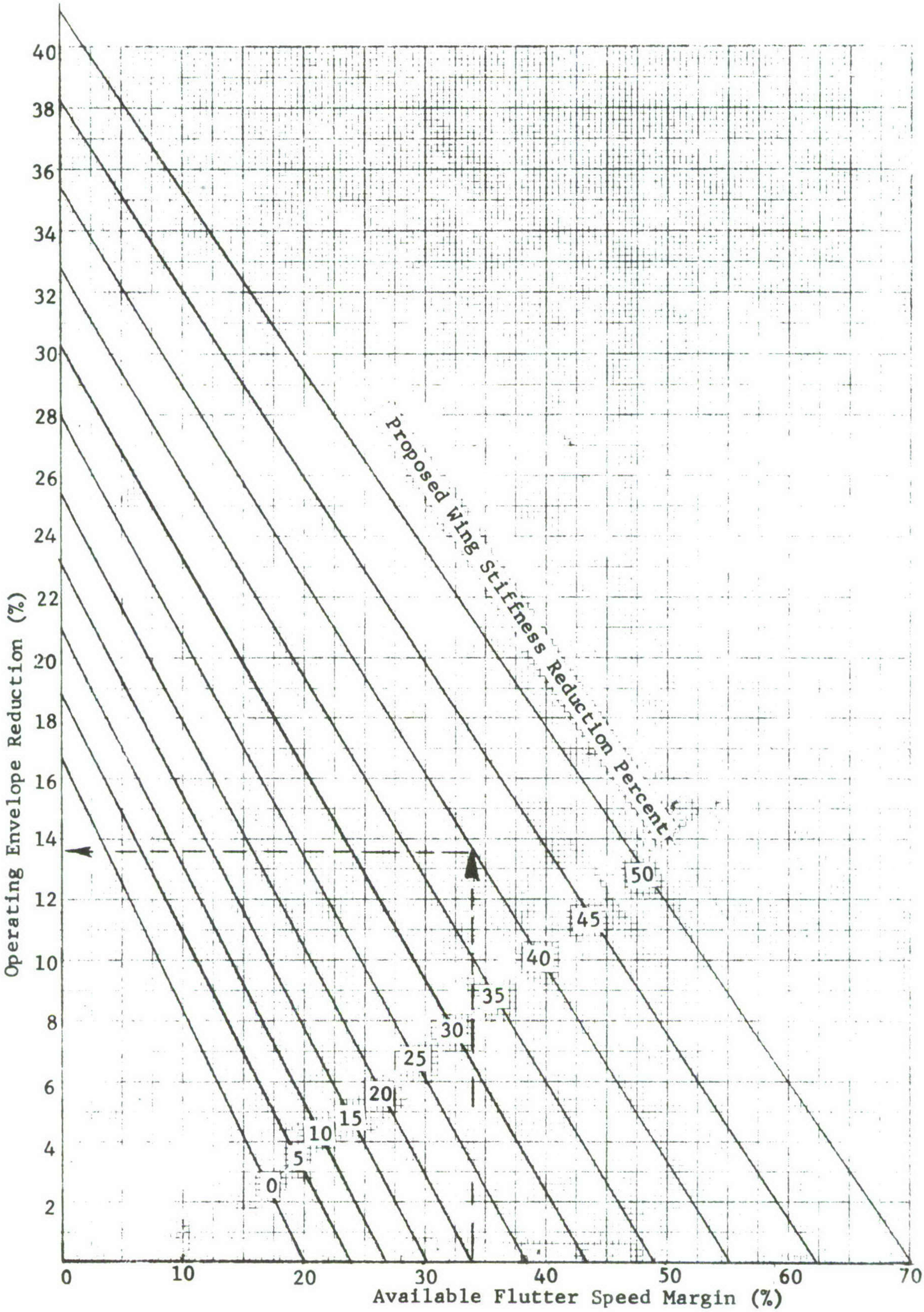
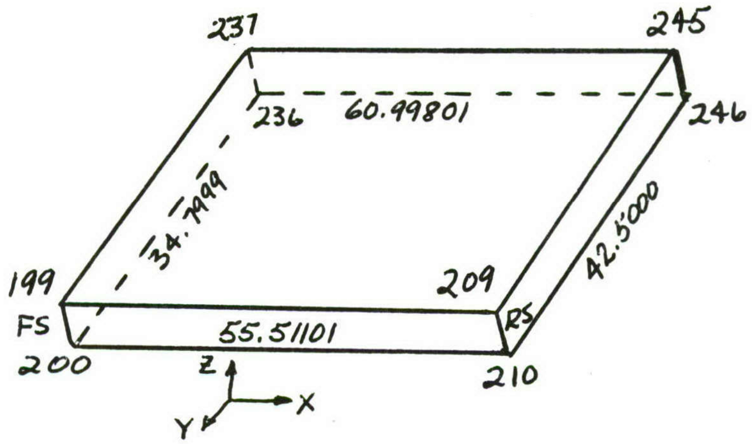


Figure 46 Operating Envelope Reductions for Various Wing Stiffness Reductions

Drawing No.
610RW000

Box torsion due to 10^6 in-lbs between nodes immediately outb'd of CSS 140:



	X	Y	Z	X	Y	Z
200	58.24899	193.29999	-2.14072	-.01770	.01718	.09365
210	113.76500	182.29999	-2.67257	-.02437	.00625	.30219
199	58.24899	193.29999	1.85078	.00674	.00698	.09365
209	113.76500	182.29999	6.14462	.03359	.00287	-.30218
236	48.19099	158.50000	-2.06219	-.00917	.01233	.06913
246	109.18900	146.79999	-3.18356	-.01642	.00462	-.18476
237	59.11699	156.29999	4.91471	.01709	.00026	.02597
245	109.18900	146.79999	6.65075	.02313	.00186	-.18476

Drawing No.
610RW000

$$\Delta Z\ (200,210) = .39584, \quad \theta = \text{ARCTAN}\ \frac{.39584}{55.51101} = .408559974^{\circ}$$

$$\Delta Z\ (199.209) = .39583$$

$$\Delta Z\ (236,\ 246) = .25389, \quad \theta = \text{ARCTAN}\ \frac{.25389}{60.99801} = .2384789495^{\circ}$$

$$\Delta\theta = .1700810245^{\circ} = 2.96847\ (10^{-3})\ \ \text{RAD}$$

$$\Delta L = \frac{42.5000 + 34.7999}{2} = 38.64995$$

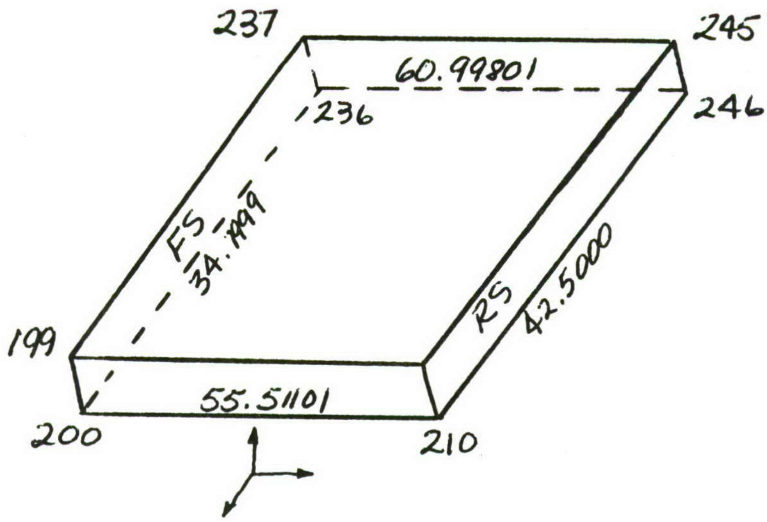
$$GJ = \frac{10^{6}\ (38.64995)}{2.96847(10^{-3})} = 13.02016(10^{9})\ \text{LB-IN}^{2}$$

$$= 90.4178\ (10^{6})\ \text{LB-FT}^{2}$$

Drawing No.
610RW002

Cells Not Effective in Torsion

Box Torsion due to 10^6 in-lbs



	X	Y	Z	X	Y	Z
200	58.24899	193.29999	-2.14072	-.04142	.03920	.26924
210	113.76500	182.29999	-2.67257	-.05745	-.00704	-.47372
199	58.24899	193.29999	1.85078	.00594	.01532	.26923
209	113.76500	182.29999	6.14462	.05807	.00531	-.47371
236	48.19099	158.50000	-2.06219	-.01817	.03075	.17531
246	109.18900	146.79999	-3.18536	-.03150	-.00199	-.26674
237	59.11699	156.29999	4.91471	.02316	.00149	.10483
245	109.18900	146.79999	6.65075	.03331	.00053	-.26674

Drawing No.
610RW002

$\Delta Z\ (200,210) = .74296,\quad \theta = \text{ARCTAN}\ \dfrac{.74296}{55.51101} = .7668015879^{\circ}$

$\Delta Z\ (199,209) = .74294$

$\Delta Z\ (236,\ 246) - .44205,\quad \theta = \text{ARCTAN}\ \dfrac{.44205}{60.99801} = .4152128216^{\circ}$

$\Delta\theta = .3515887663 = 6.13638\ (10^{-3})\ \text{RAD}$

$\Delta L = 38.64995$

$$GJ = \frac{10^{6}\ (38.64995)}{6.13638(10^{-3})} = 6.29849\ (10^{9})\ \text{Lb-In}^2$$

$$= 43.73951\ (10^{6})\ \text{Lb-Ft}^2$$

MATH MODEL WITH CELLS EFFECTIVE IN TORSION Dwg. No. 610RW002

Due to 100,000 in-lbs torsion

Δ_z at Node 777: - .00678 in

Δ_z at Node 27: .00678 in

$(X)_{777} = 112.07280$ $(Y)_{777} = 169.17130$

$(X)_{27} = 65.17020$ $(Y)_{27} = 178.96999$

46.90260 8.89869

$$(46.90260)^2 + (8.89869)^2 = 47.73930 \text{ in}$$

$$\text{SIN } \theta = 2(.00678)/47.73930 = 2.84043\ (10^{-4})$$

$$\theta = .01627\ ^\circ/100,000 \text{ in-lbs}$$

$$GJ = \frac{100,000(22.5167)}{.01627} = 138.393,734 \quad \frac{\text{Lbs.in}^2}{\text{Deg.}}$$

$$GJ = \frac{138,393,734(180)}{144\ (\quad)} = 55,065,117 \quad \frac{\text{Lbs ft}^2}{\text{Radian}}$$

* This model represents 22 inches outboard of CSS 140 with all cell material. The number of elements limits the total size of the model.

Stiffness Reduction = 90.4178 (10^6) - 43.73951 (10^6)
= 46.67829 (10^6)

$$\frac{46.6783}{90.4178} = 51.63\%$$

Using model with cell stiffness (same location)

GJ = 55.065 (10^6) Lbs-ft^2 and stiffness reduction

= 90.4178 (10^6) lbs-ft^2 and stiffness reduction

$$\frac{35.3528\ (10^6)}{90.4178\ (10^6)} = 39.10\%$$

V.6 SAMPLES OF USE OF FINITE ELEMENT MODELS FOR DESIGN DETAILS

Figure 47 is a portion of the baseline wing finite element model with a circular cutout in the lower surface for the inboard pivoting pylon at Center Spar Station 120. This model was loaded with condition F400A while using various schemes for metal placement around the cutout.

Figures 48 and 49 is the lower skin of the portion of the model of Figure 47. The structure immediately around the cut-out is shown in detail in Figures 50 and 51 with principal stresses printed in the plate elements. Stresses outboard of the cutout and around the cutout can be compared for selection of reinforcement. In this example the net area through the cutout is equal to the section area before the cutout was made.

Figure 52 models the stresses in the lower skin flap attachment tabs when 50 ksi are applied to the lower surface bending material. Constant stress areas are shaded.

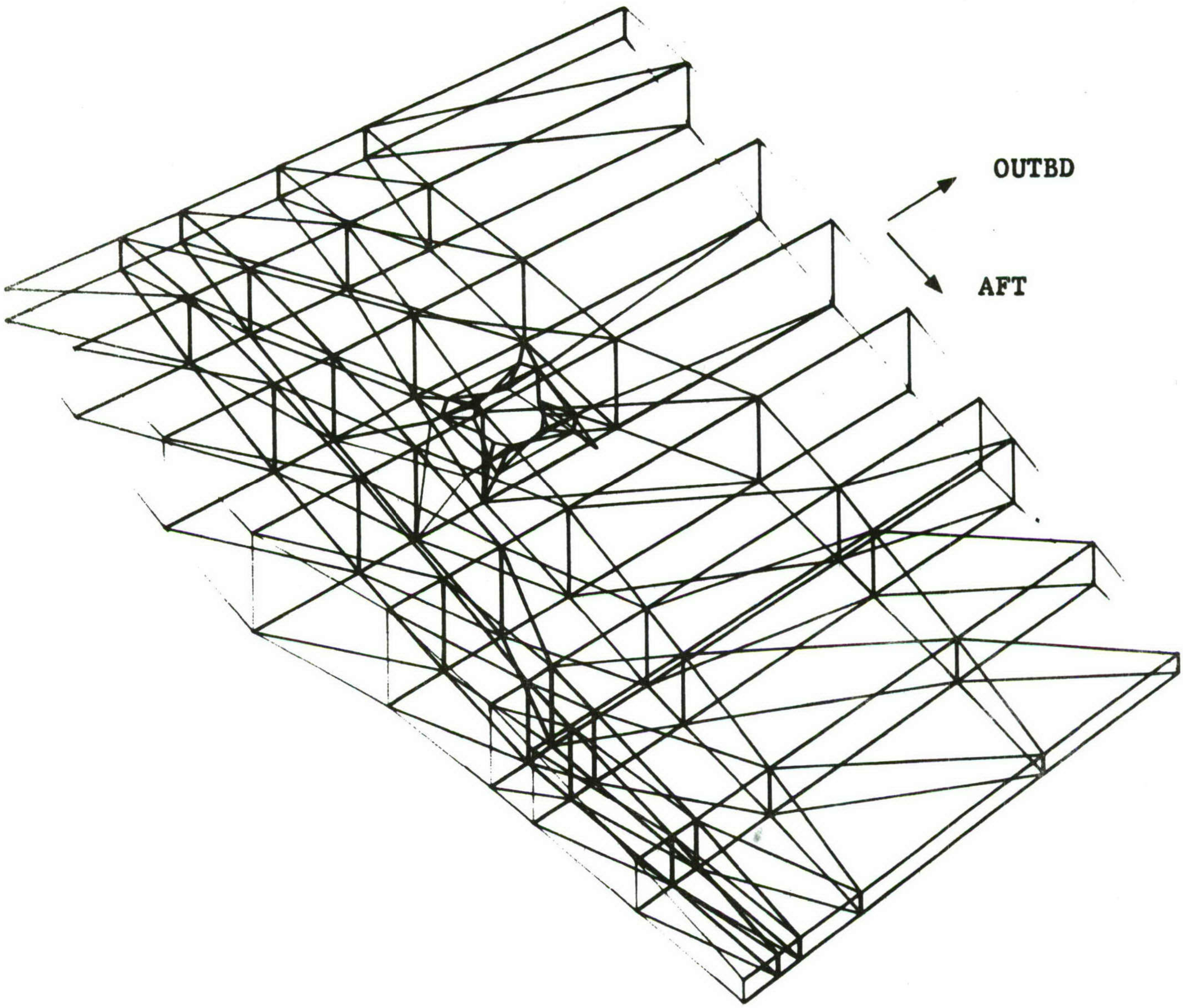


Figure 47 Portion of Baseline Wing Finite Element Model with Inboard Pivoting Pylon Cutout

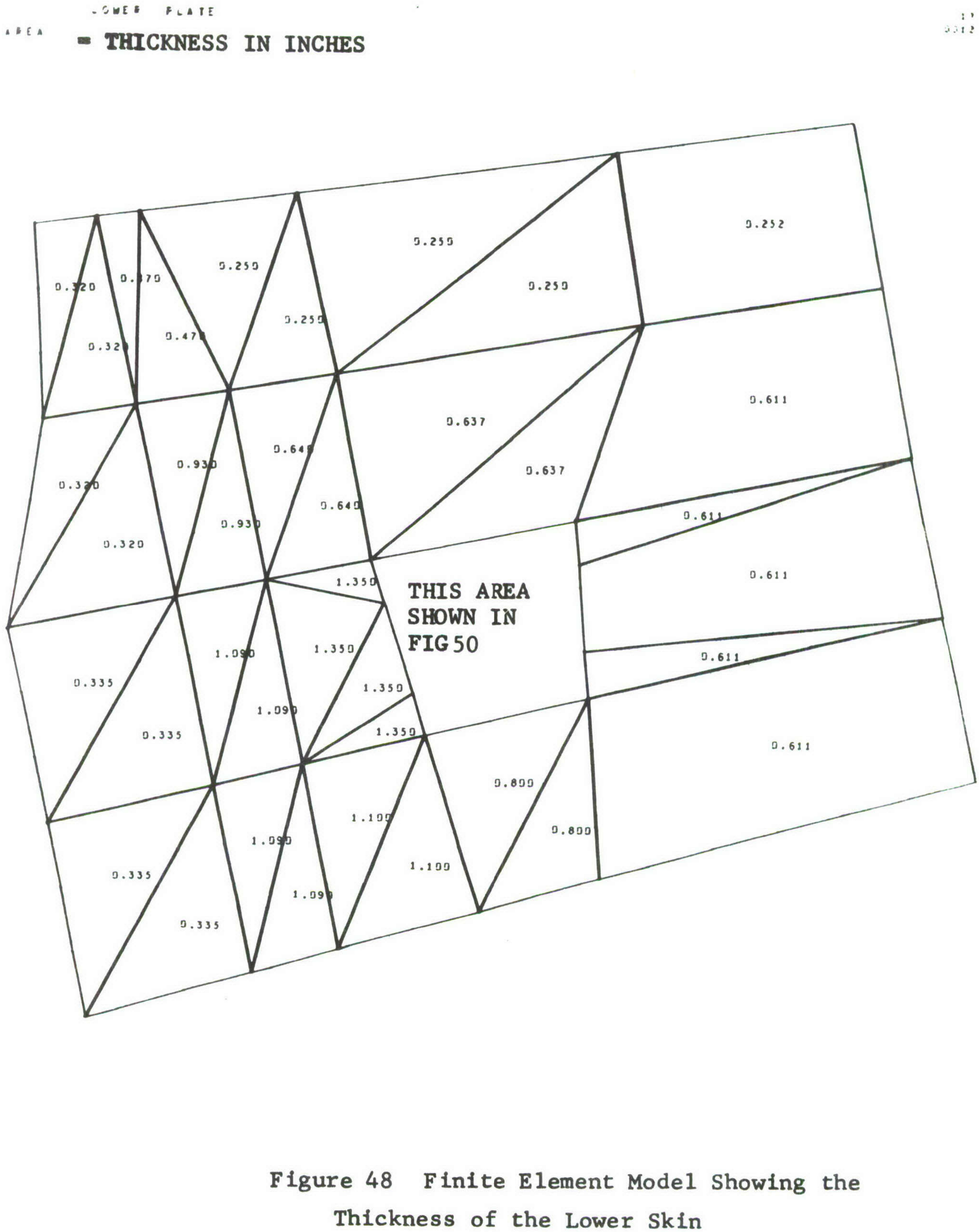


Figure 48 Finite Element Model Showing the Thickness of the Lower Skin

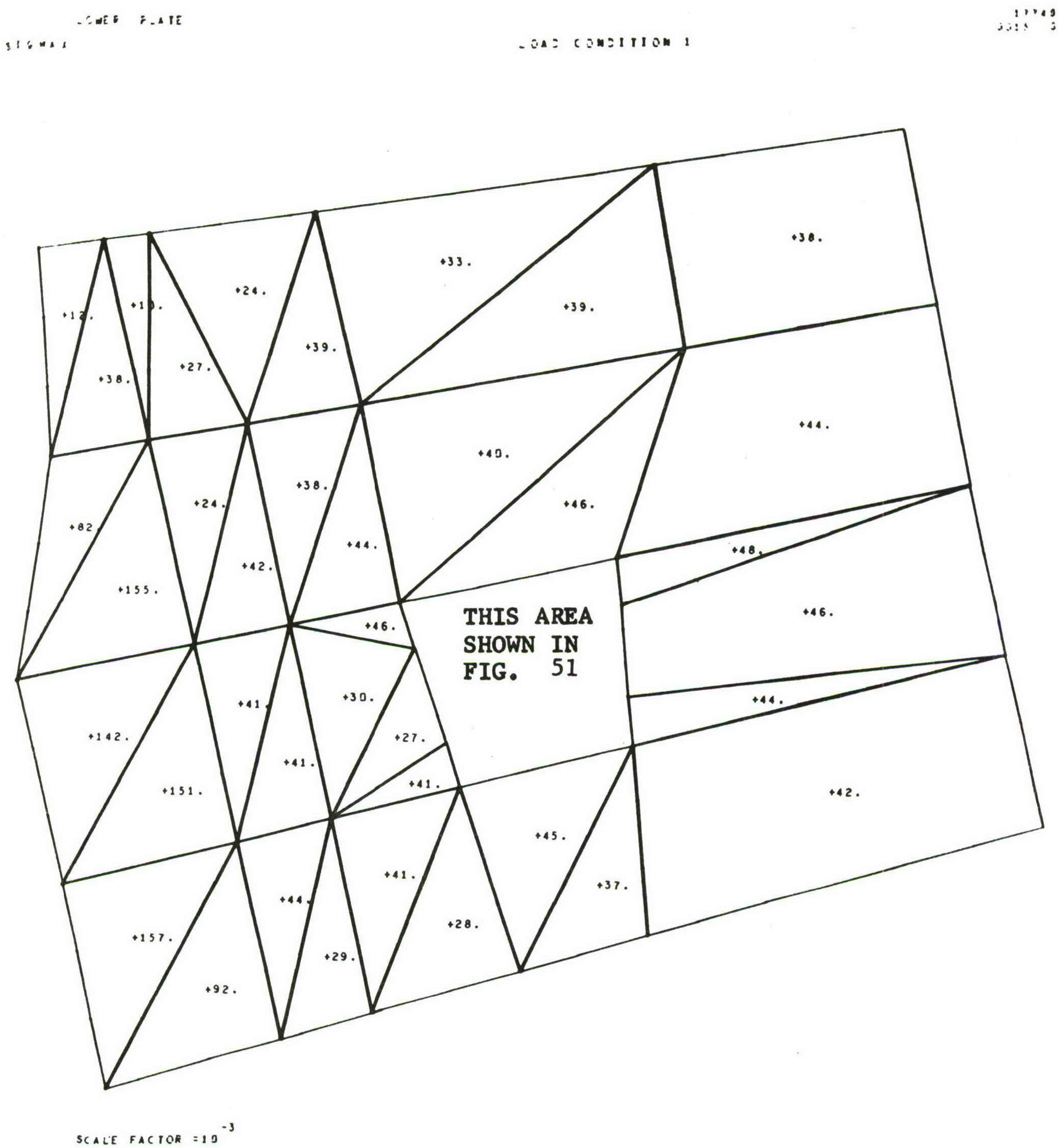


Figure 49 Finite Element Model Showing the Principal Stresses in the Lower Skin

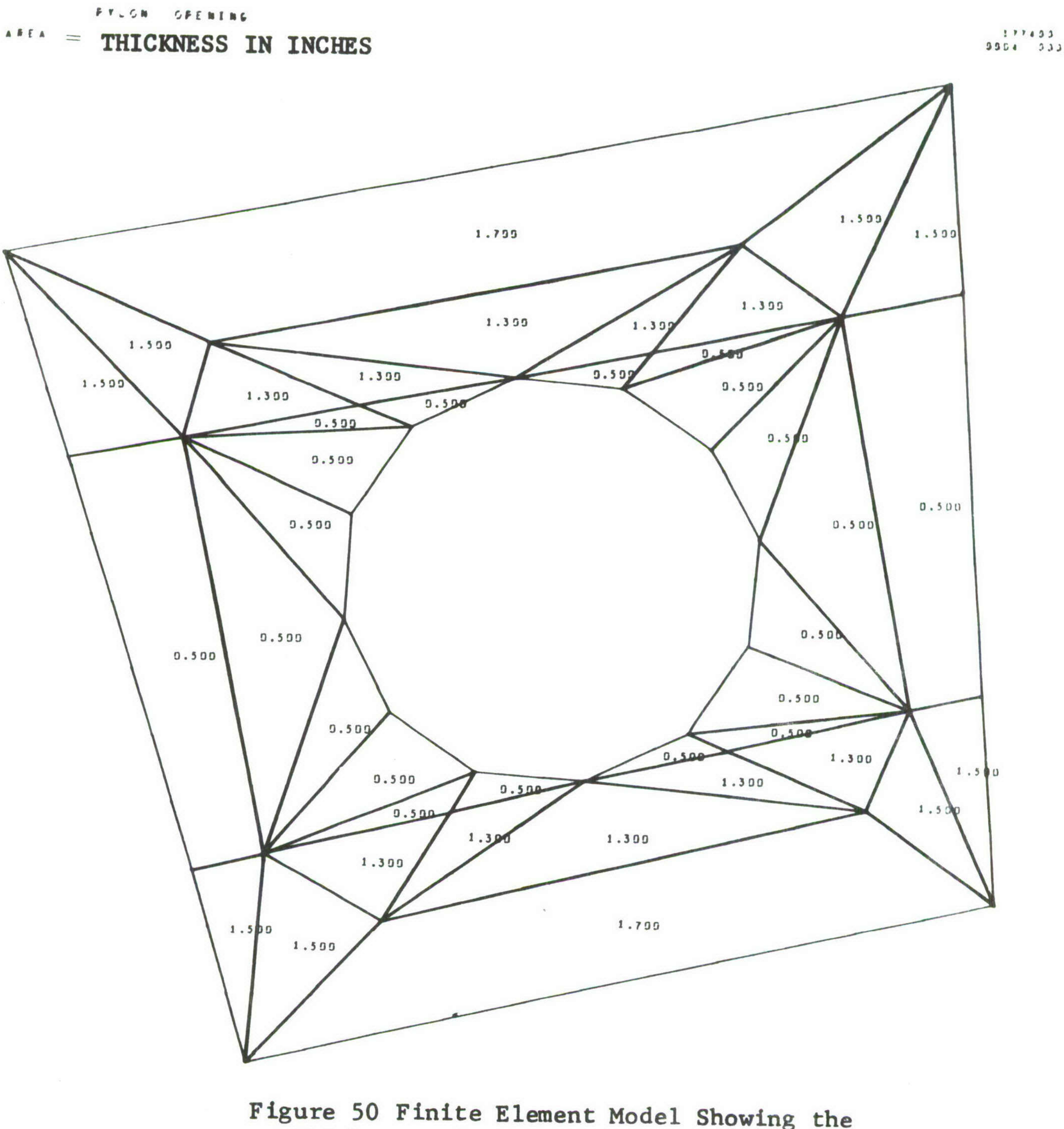


Figure 50 Finite Element Model Showing the Thickness of the Lower Skin Around the Cutout for the Inboard Pivoting Pylon

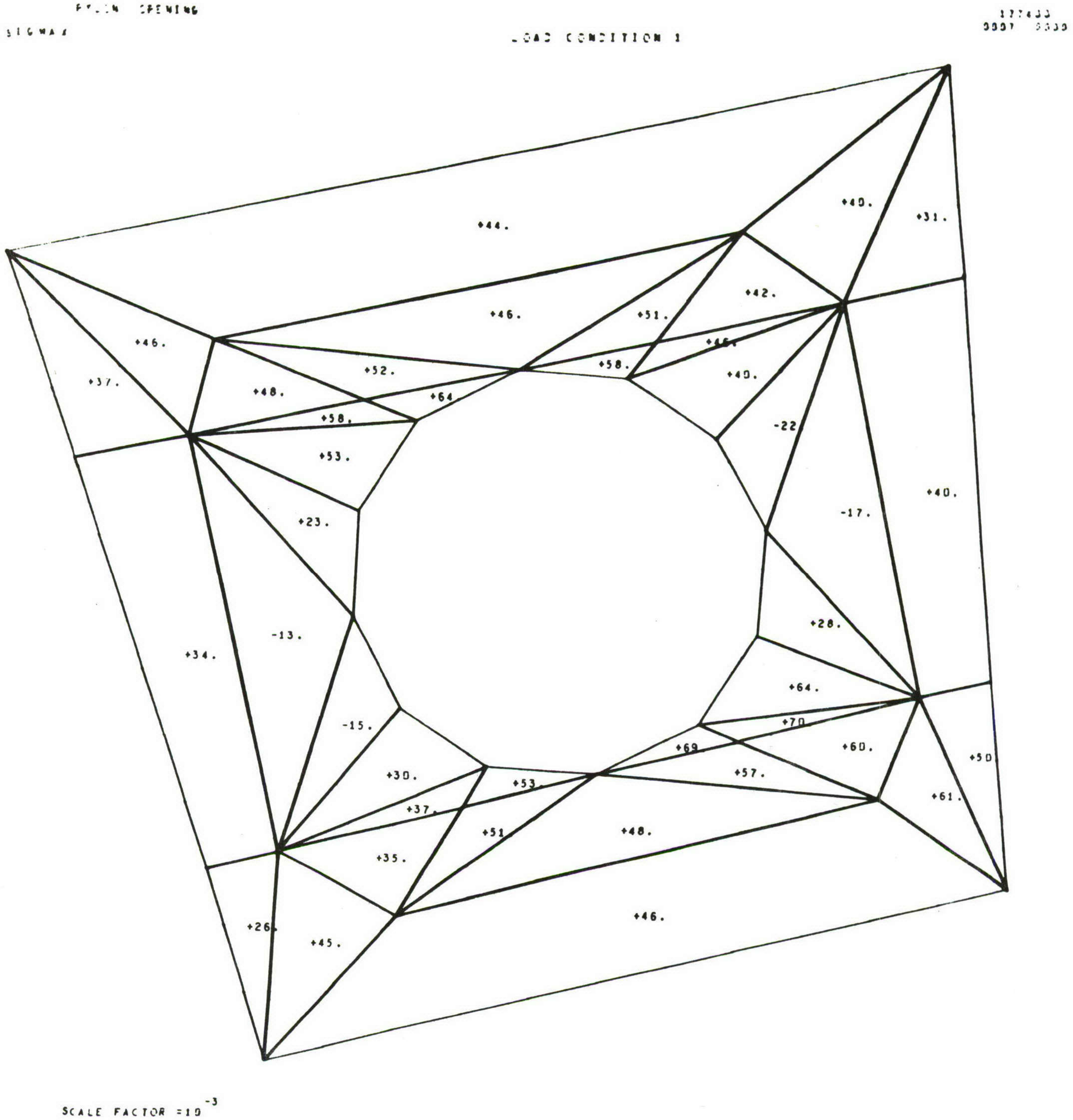


Figure 51 Finite Element Model Showing the Principal Stresses in the Lower Skin Around the Cutout for the Inboard Pivoting Pylon

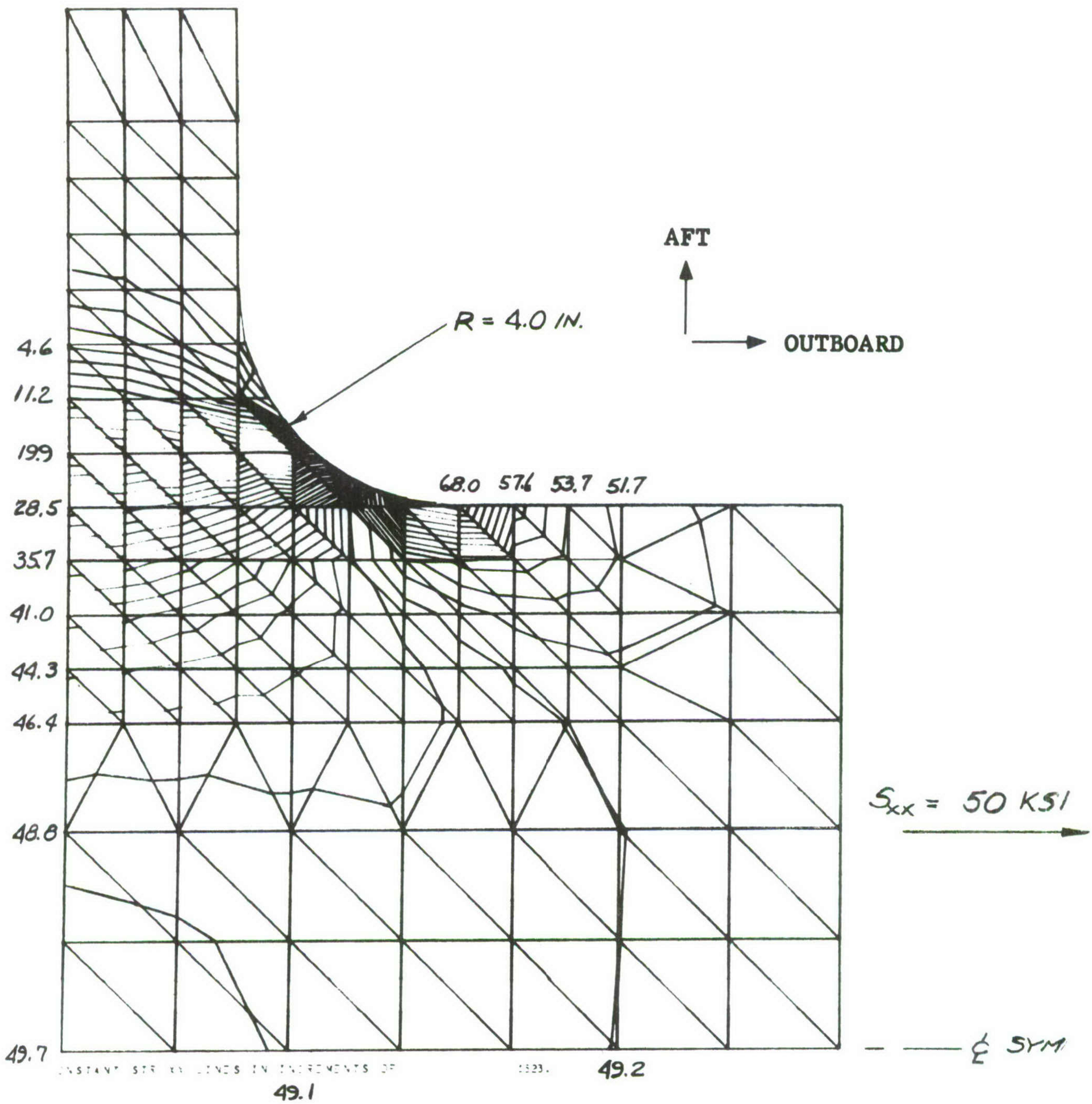


Figure 52 Finite Element Model Showing the Lower Skin Flap Attachment Tab

V.7 ESTIMATE OF WEIGHT SAVED BY REMOVAL OF LOWER SURFACE FASTENERS

It is possible to make an estimate of the factors contributing to weight savings. For this purpose it is convenient to compare Analytical Assemblies 610RA000 (Baseline at CSS 140) and 610RA006 (Laminated Lower Skin/Corrugated Spar at CSS140).

The weights given below show approximately 23% weight reduction. The greatest reduction is in the weight of the lower skin. It must be noted, however, that the surface stresses are optimum only locally and that sealing requires material that cannot be used efficiently.

The 610RA000 assembly lower surface is sized for a maximum stress of 20.80 KSI*. Figure 53 allowables would permit a theoretical weight reduction of 19.46% as shown below, due exclusively to elimination of holes.

Changing material to 7050-T76 and eliminating the holes would permit a 44.28% weight reduction of the lower surface. This is illustrated below with the aid of Figure 54.

Changing material to 7050-T76 without eliminating the holes would permit a 20.08% weight reduction based on Figure 55.

These estimates are useful for observing that in the case considered approximately half the weight saved is due to material change and half is due to elimination of fastener holes.

*Note that this stress was lowered to 19.60 KSI for preliminary design wings.

Drawing No.
610RA000/610RA006

DISTRIBUTION OF WEIGHT SAVINGS (A1)

			610RA000		610RA006
A	Wt of Lwr Skin	=	176.44 Lbs	34% =	115.79 Lbs.
	1/2 Spar Wts	=	33.01		26.86
			209.45	32%	142.63
B	Wt of Upr Skin	=	130.68 Lbs		122.82
	1/2 Spar Wts		33.01		26.87
			163.69	-8.6%	149.69
			384.89		296.94

Baseline Wts (A) are due to operating at 39.0 KSI (Ultimate) because of material properties, hole effects and other design features.

$$209.45 - 142.63 = 66.82$$

$$66.82/209.45 = .32 = 32\%$$

Baseline Wts (B) are greater than 610RA006 Wts (B) because of wider spar spacing, lesser spar torsional rigidity and machined spars.

$$163.69 - 149.69 = 14.00$$

$$14.00/163.69 = .09 = 9\%$$

Baseline Wts (C) are greater due to Lwr Skin Bolts

1. Effect of removal of Lwr Skin holes on 2024-T81

   Baseline stress used with wts shown - 20.70 KSI (MAX. OPRTG). allowable baseline Lwr Skin stress without holes = 25.80 KSI (For 2000 Hr depot inspectable slow crack growth)

   $$\text{Possible weight saving} = 1 - \frac{20.70}{25.70} = 19.46\%$$

   (Ref: Figure 53)

Drawing No.
610RA000/610RA006

2. Effect of changing from 2024-T81 to 7050-T76 and removing holes, using part through surface crack 8000 hr slow crack growth allowables:

$$\text{Possible weight saving} = 1 - \frac{20.70}{30.00} = 31.00\%$$

(Ref: Figure 54)

3. Effect of changing from 2024-T81 to 7050-T76 (leaving holes, as in baseline)

$$\text{Possible weight saving} = 1 - \frac{20.70}{25.90} = 20.08\%$$

(Ref: Figure 55)

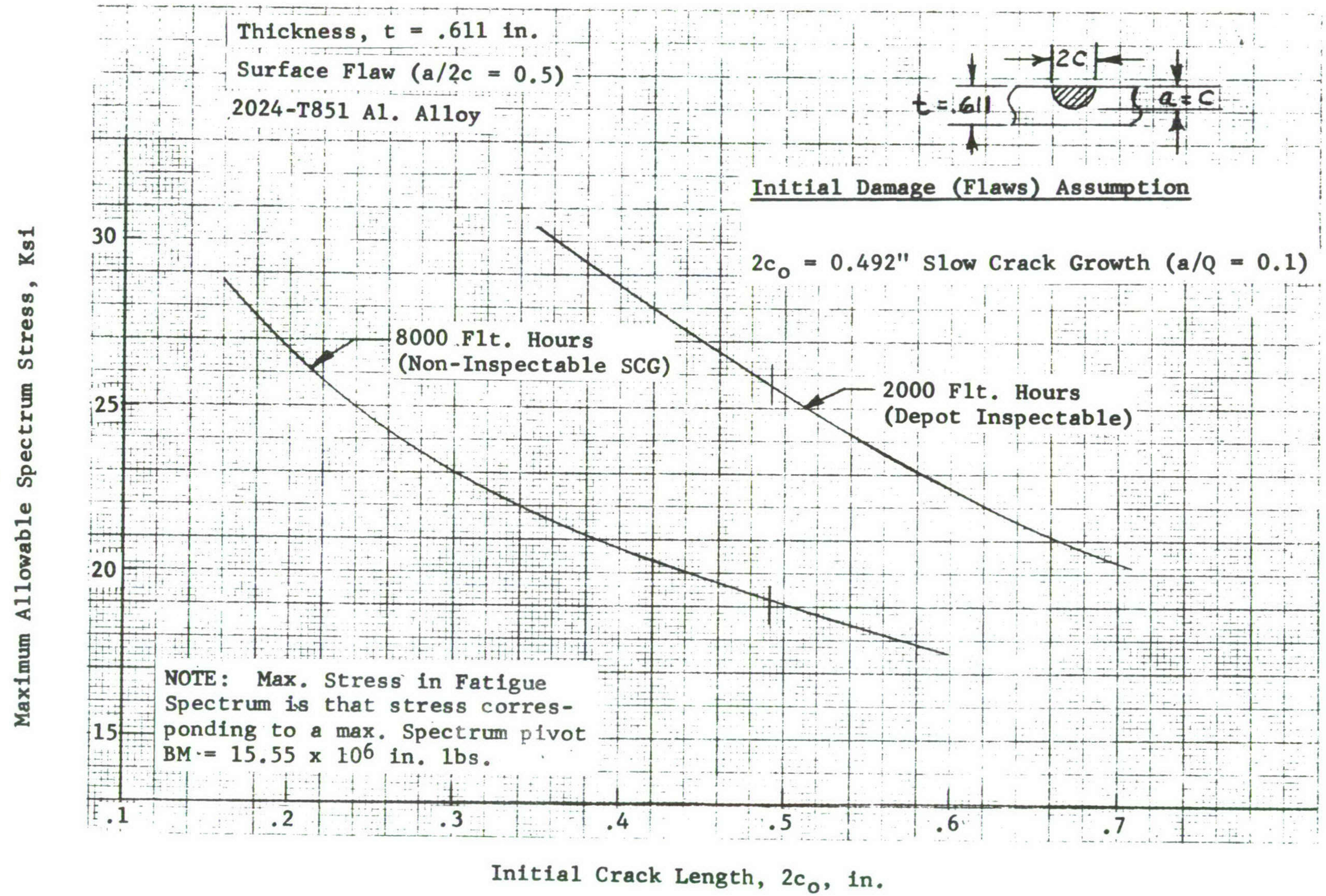


Figure 53 F-111F C.S.S. 140 Lower Surface

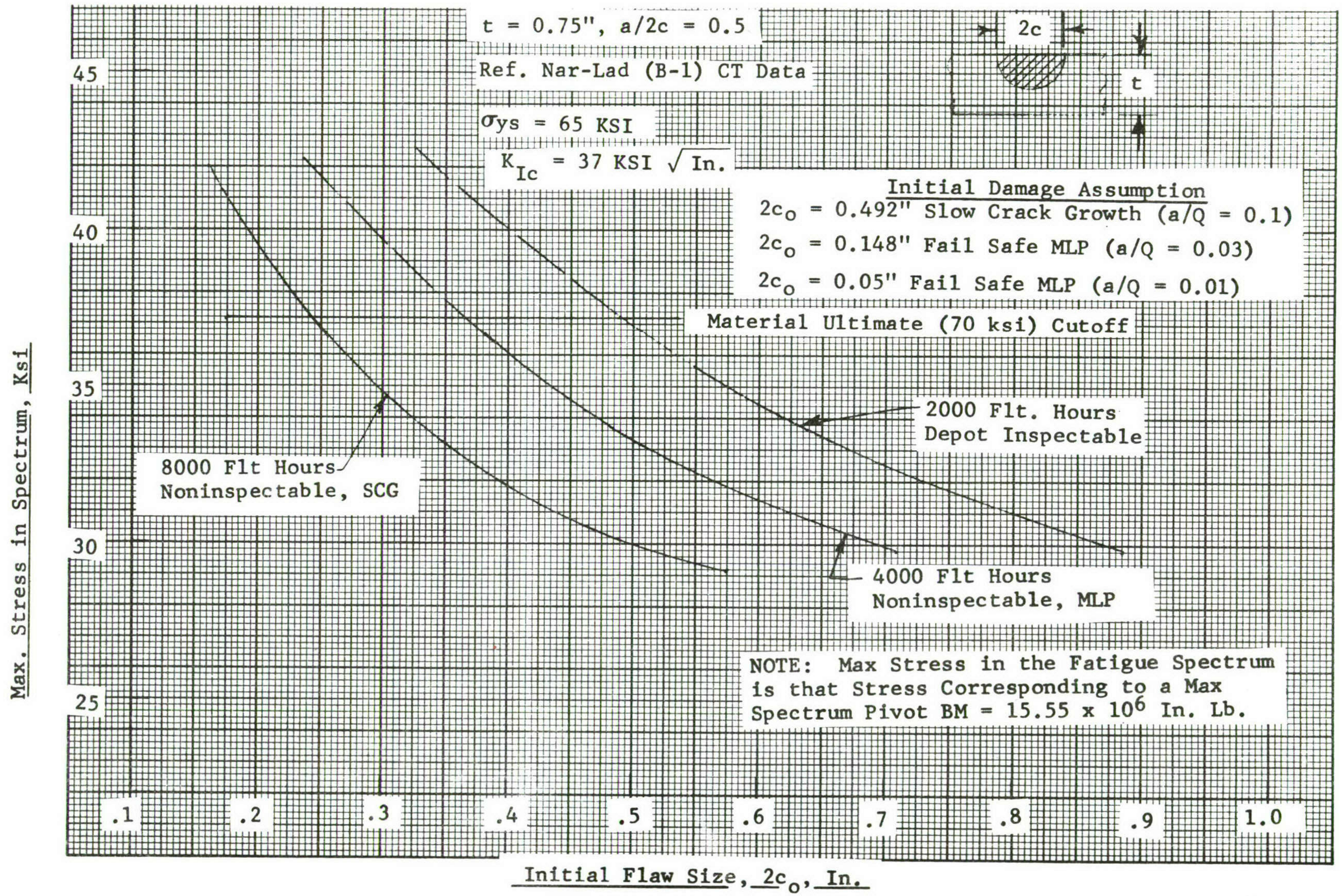


Figure 54 Phase IA Fracture Design Allowables
7050 Al. Alloy Pl.
Part Through Surface Crack

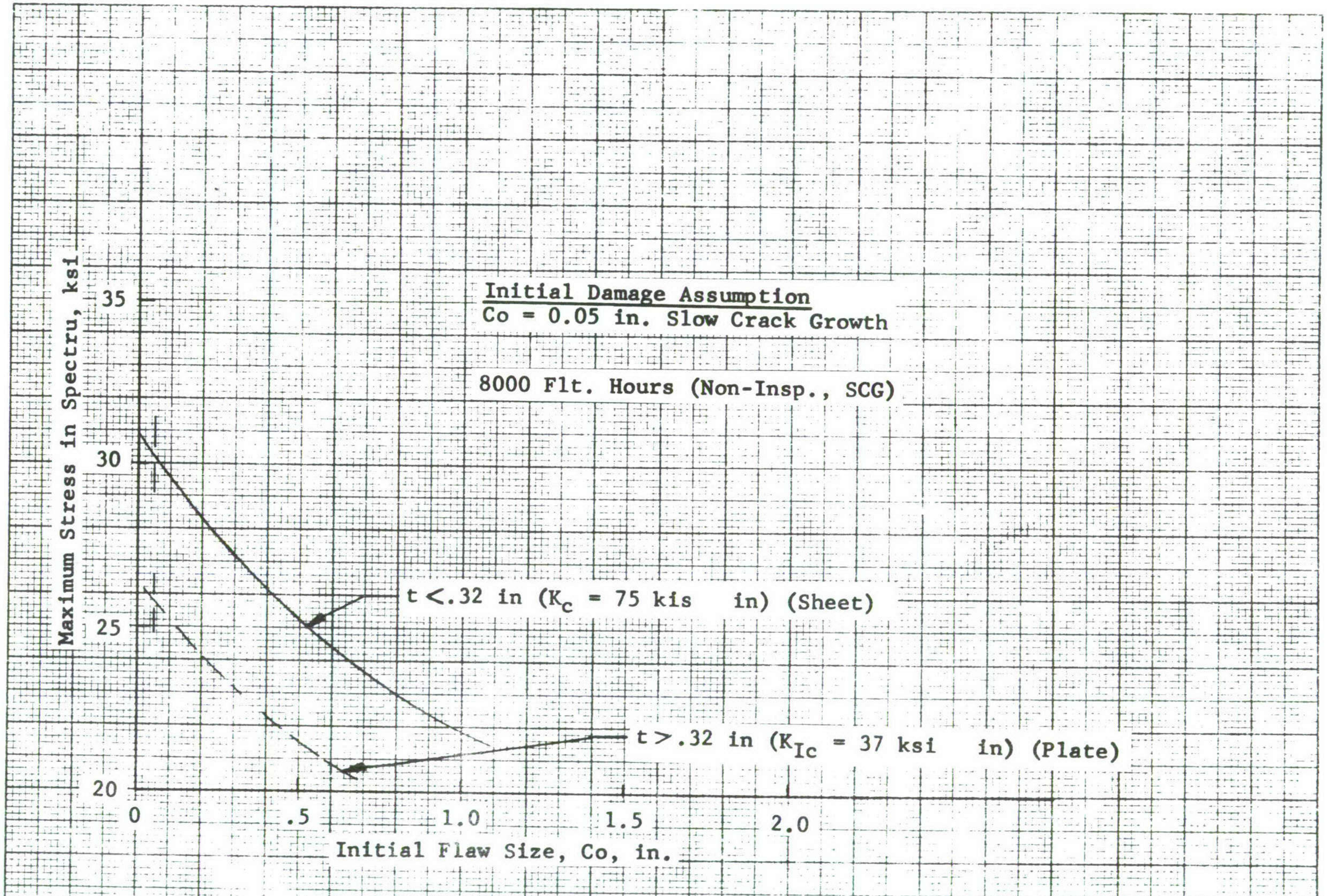


Figure 55 C.S.S. 140 7050 Al. Alloy 5/16 Bolt Hole Through Crack

APPENDIX VI

FATIGUE AND FRACTURE ANALYSIS

VI.1 FATIGUE DESIGN DATA

Additional details concerning development of fatigue design data and the preliminary S/N data assumed for new materials early in Phase IA are presented in this section.

The procedure used to develop sufficient fatigue analyses to allow determination of fatigue design allowables and determination of fatigue damage for intermediate K_T's by crossplotting is described as follows:

1. Net wing pivot bending moment loads spectra including occurrences representing a 4000-hour lifetime are input as loads libraries in terms of mean and alternating loads.

2. The loads spectra are converted into corresponding mean and alternating stress spectra by using the appropriate unit stress coefficient adjusted to include F_{T_u} and elevated temperature corrections as required.

3. S-N data reflecting the range of stress concentrations required are input as a library.

4. Using IBM 370 computer procedure TX3, fatigue damage (summation of n/N) is calculated for each S-N library using a range ($\pm$10% increments) of factors on the unit stress coefficient.

5. The resulting damage multiplied by an S.F. = 4.0 may be plotted to achieve two purposes:

   (a) Plot damage versus stress level (limit, ultimate or maximum spectrum stress level) for each K_T, enter the curves at $\Sigma n/N = 1.0$ (failure using Miner's rule), and determine the allowable stress levels. Holding design stresses below the allowable enables a design to meet the fatigue requirement. Plotting the allowable stress versus K_T yields the fatigue design data sheet.

(b) The damage for intermediate K_T's at a selected control point may be determined by cross plotting the damage developed for available S-N data reflecting other K_T values, e.g., plot the damage calculated for K_T = 2.0, 3.0, and 4.0 to allow determination of damage at 3.4.

The baseline pivot bending moment spectra is presented in paragraph VI.2, and the unit stress concept is discussed in paragraph VI.5.

Corrections to account for the difference in strength of the material used in fabrication and of the material used in generating S-N data (called F_{Tu} corrections) are made by ratioing F_{Tu} values. Corrections to account for the reduction in fatigue data due to elevated temperature are made by ratioing the material ultimate strength at elevated temperature and at room temperature. The F_{Tu} correction established for the baseline 2024-T851 aluminum is 1.0144. Elevated structural temperatures and corresponding corrections established for the baseline are given in Table XXIX. F_{Tu} corrections for the 7000 series aluminum alloys and the 8-8-2-3 titanium alloy were neglected in Phase IA due to the preliminary nature of the design effort. It was felt that 8-8-2-3 titanium would experience no degradation in strength at the baseline temperature of 255°F. This was substantiated by data issued bu AFML in F33615-72-C-1280, dated March 1973, which indicated no difference in K_T = 3 S-N data generated for 400°F and room temperature. The only flight condition thought to affect the 7000 series aluminums was Condition 9, where the temperature is 255°F. The total exposure time in the 4000-hour fatigue spectrum is only 9.1 hours; however, fatigue analyses using S-N data for these alloys reflect a temperature correction for this condition corresponding to a 20% strength reduction. This was substantiated by tensile strength test data generated for 7050-T73651 aluminum plate where the average F_{Tu} reduction was 19% after exposure for 10 hours at 270°F. This test data is included in Appendix VIII of this report.

Because sufficient fatigue S-N data was not available for the new materials being evaluated early in Phase IA, an attempt was made to assemble data which was available and representative of the actual data required. This representative data was used to prepare initial design data sheets until test data could be generated. The S-N data shown in Figures 56 through 58 for 7075-T6 aluminum sheet was available at Convair Aerospace as computer S-N libraries. This data is from NACA TN3866 and agrees

Table XXIX

BASELINE WING ELEVATED TEMPERATURE CORRECTIONS
FOR FATIGUE ANALYSIS

2024-T851 Aluminum

SPECTRUM COND. NUMBER	STRUCTURAL TEMPERATURE, °F	CORRECTION FACTOR*
1	87	1.0152
2	106	1.0229
3	87	1.0152
4	106	1.0229
5	127	1.0308
6	113	1.0229
7	255	1.1167
8	RT	NA
9	RT	NA

*Obtained from contractor document FZS-12-141, "F-111 Design Allowables," dated 1 August 1966.

very well with similar data in MIL-HDBK-5A. Using adjustments based on a ratio of F_{T_u} values, this data was used to simulate data for the 7475 and 7050 aluminum alloys. This seemed a reasonable approach based on some limited S-N data from Alcoa for 7475 and 7050 for $K_T = 1$ and $K_T = 3.0$. The 6Al-4V annealed titanium S-N data shown in Figures 59 through 61 was also available as computer libraries and was used to represent all titaniums by adjusting stresses with a ratio of ultimate strengths.

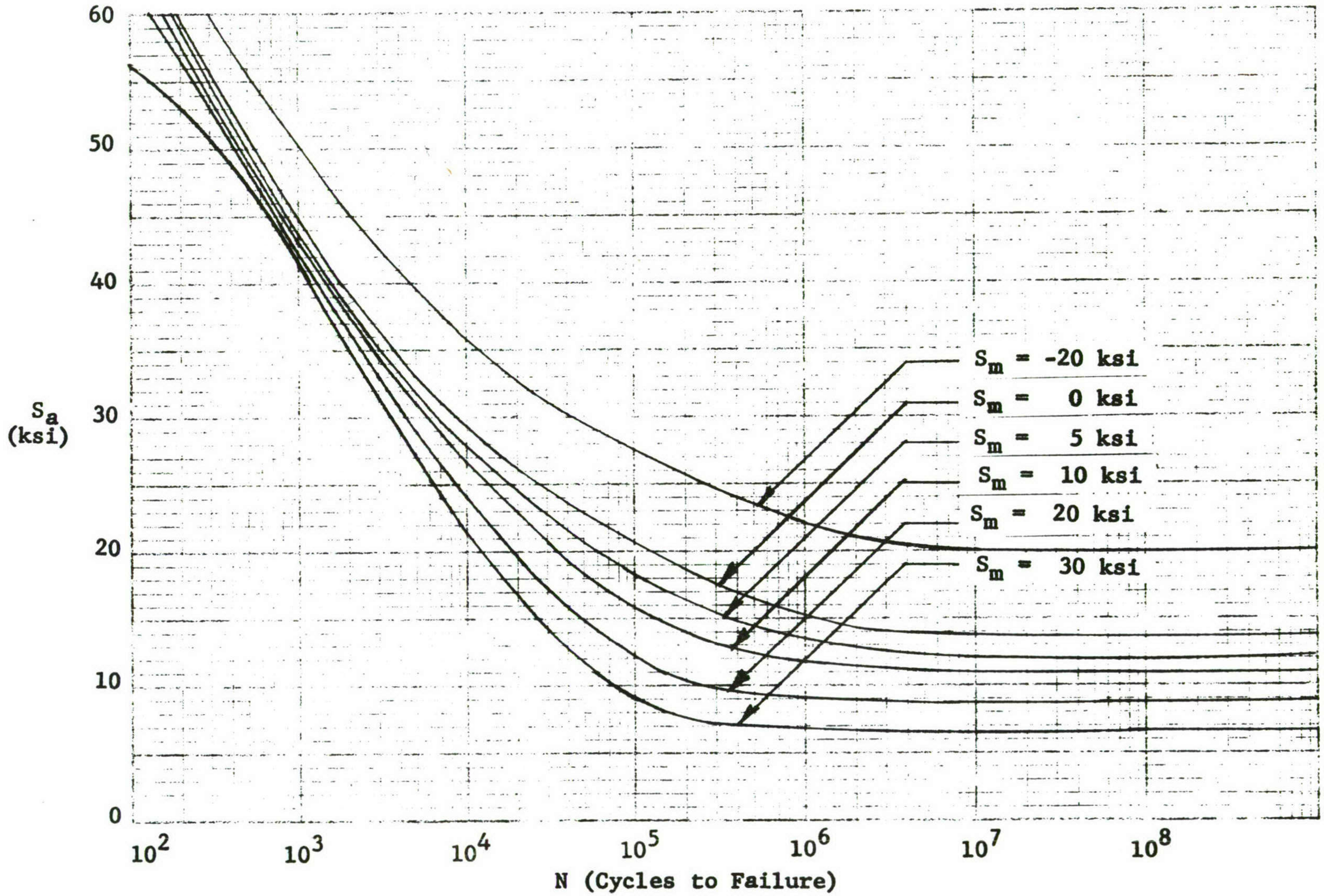


Figure 56 S-N Curves 7075-T6 Aluminum Sheet, $K_T = 2.0$

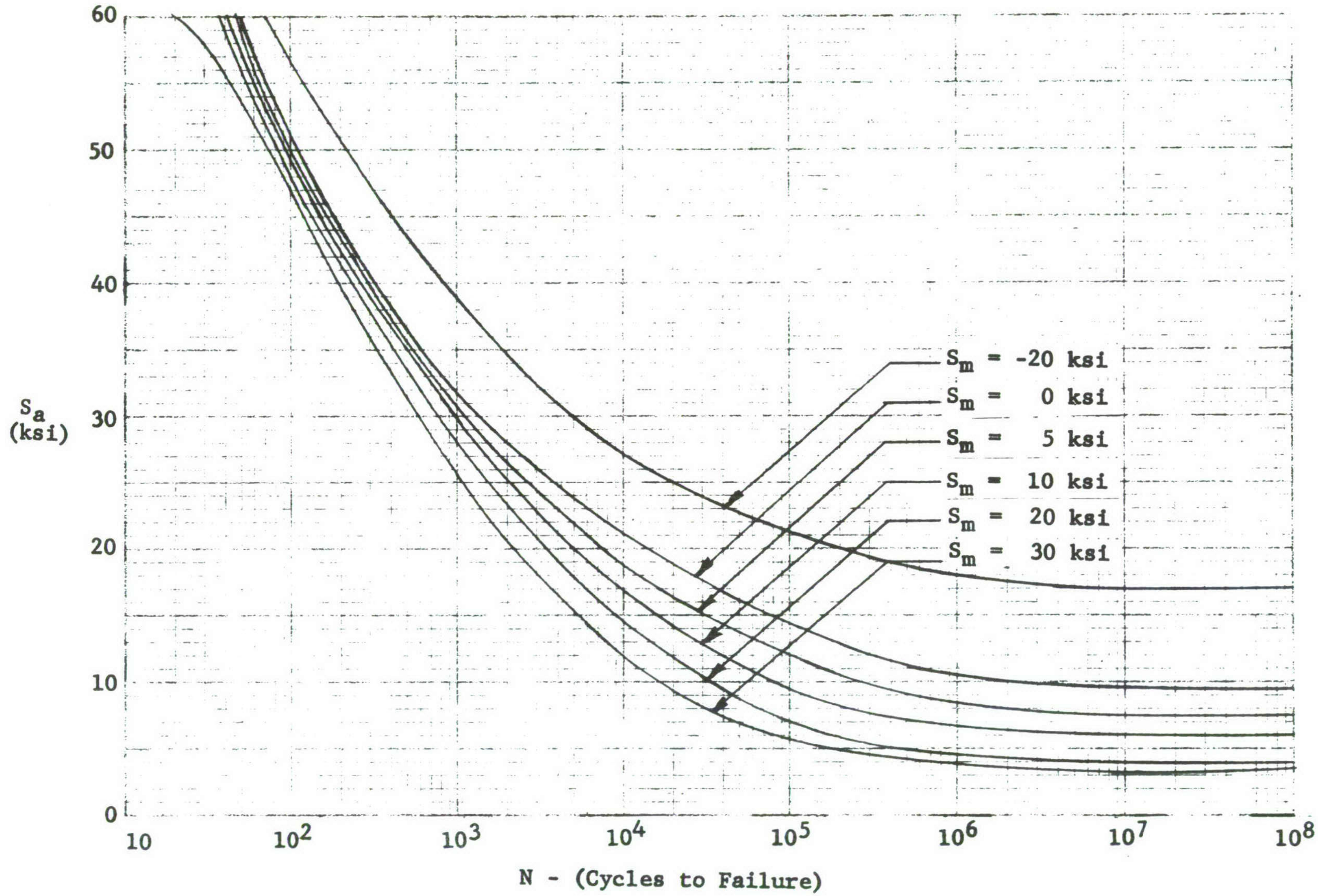


Figure 57 S-N Curves 7075-T6 Aluminum Sheet, K_T = 3.0

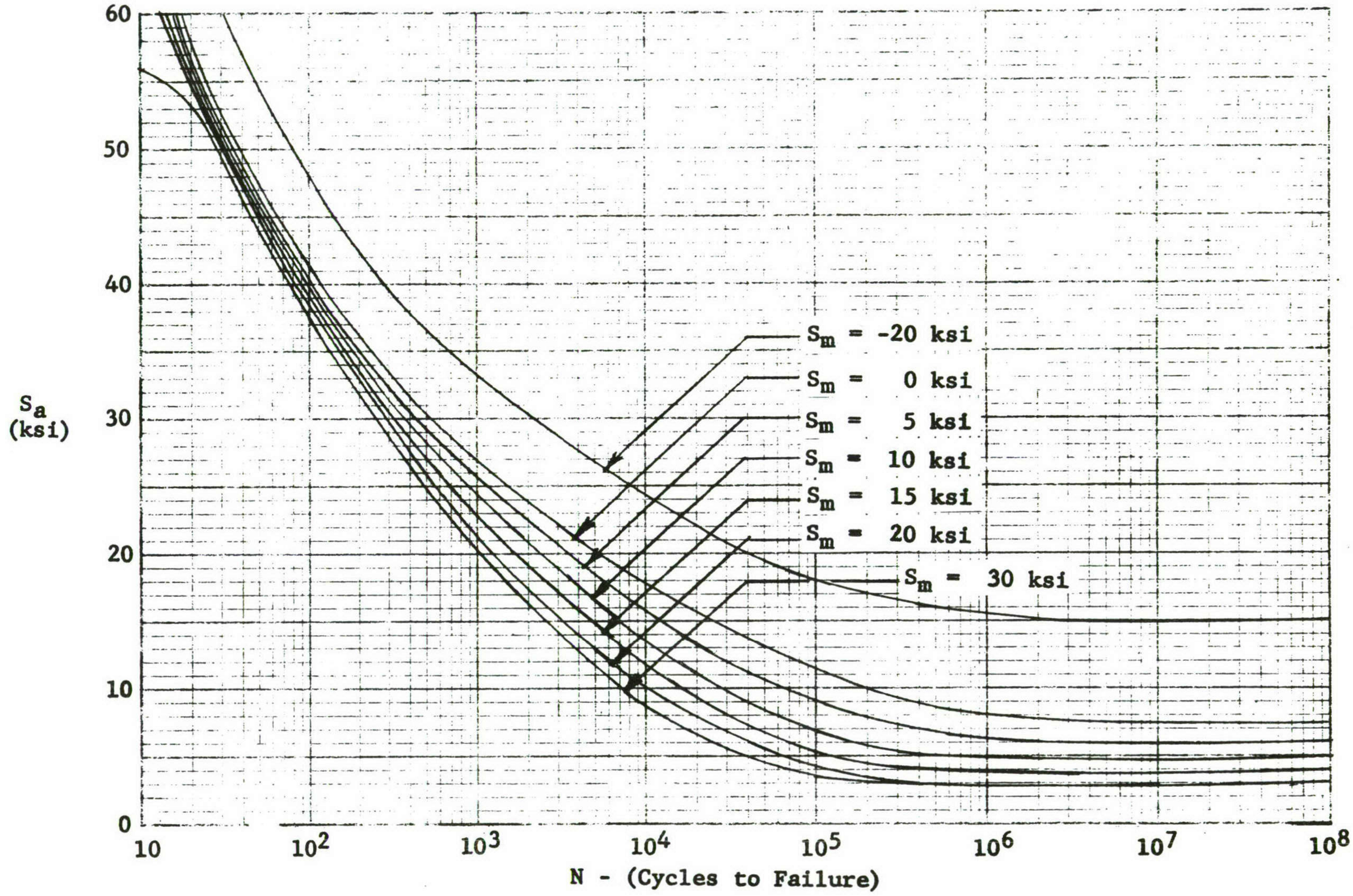


Figure 58 S-N Curves 7075-T6 Aluminum Sheet, $K_T = 4.0$

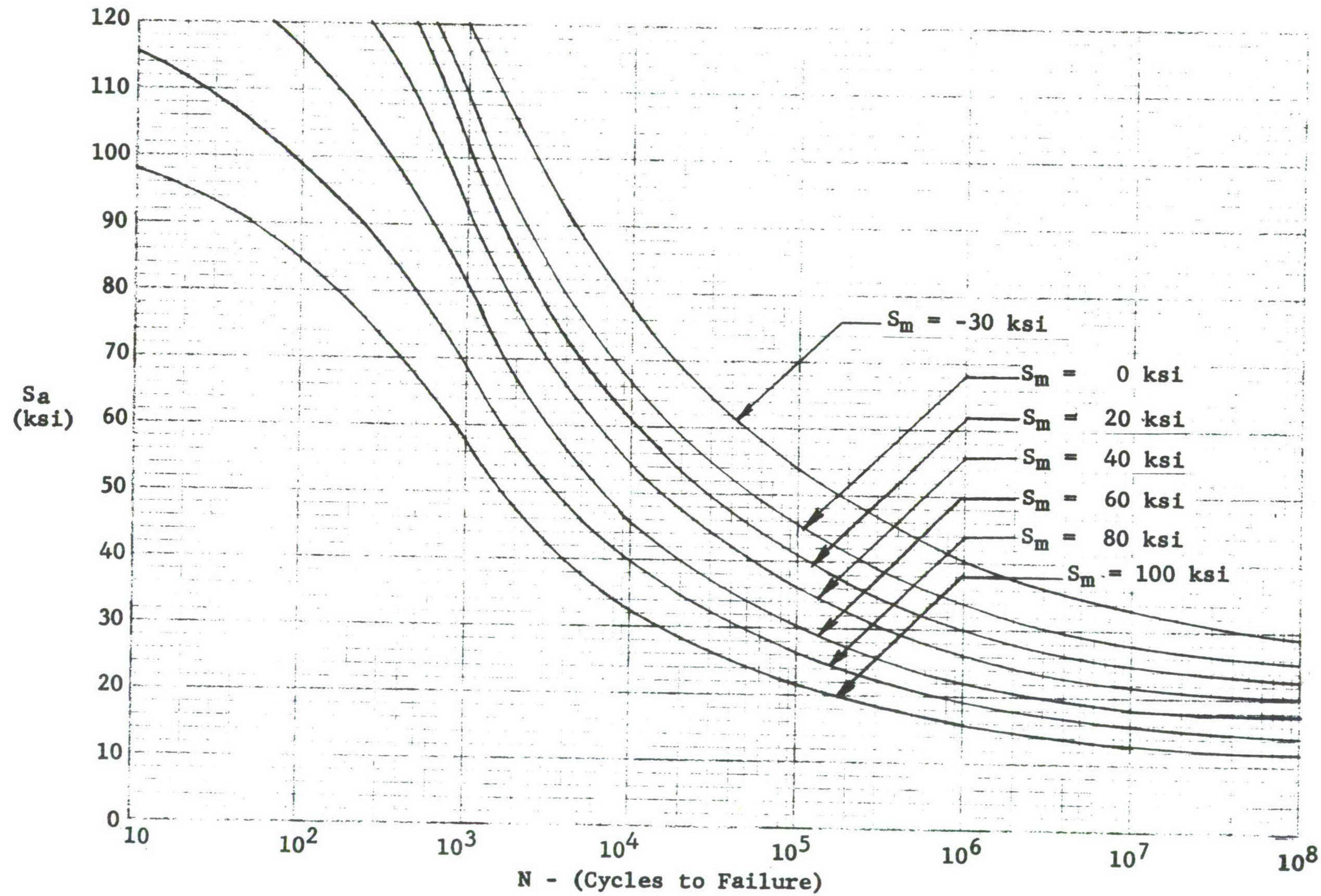


Figure 59 S-N Curves 6Al-4V Titanium Annealed Plate, K_T = 2.0

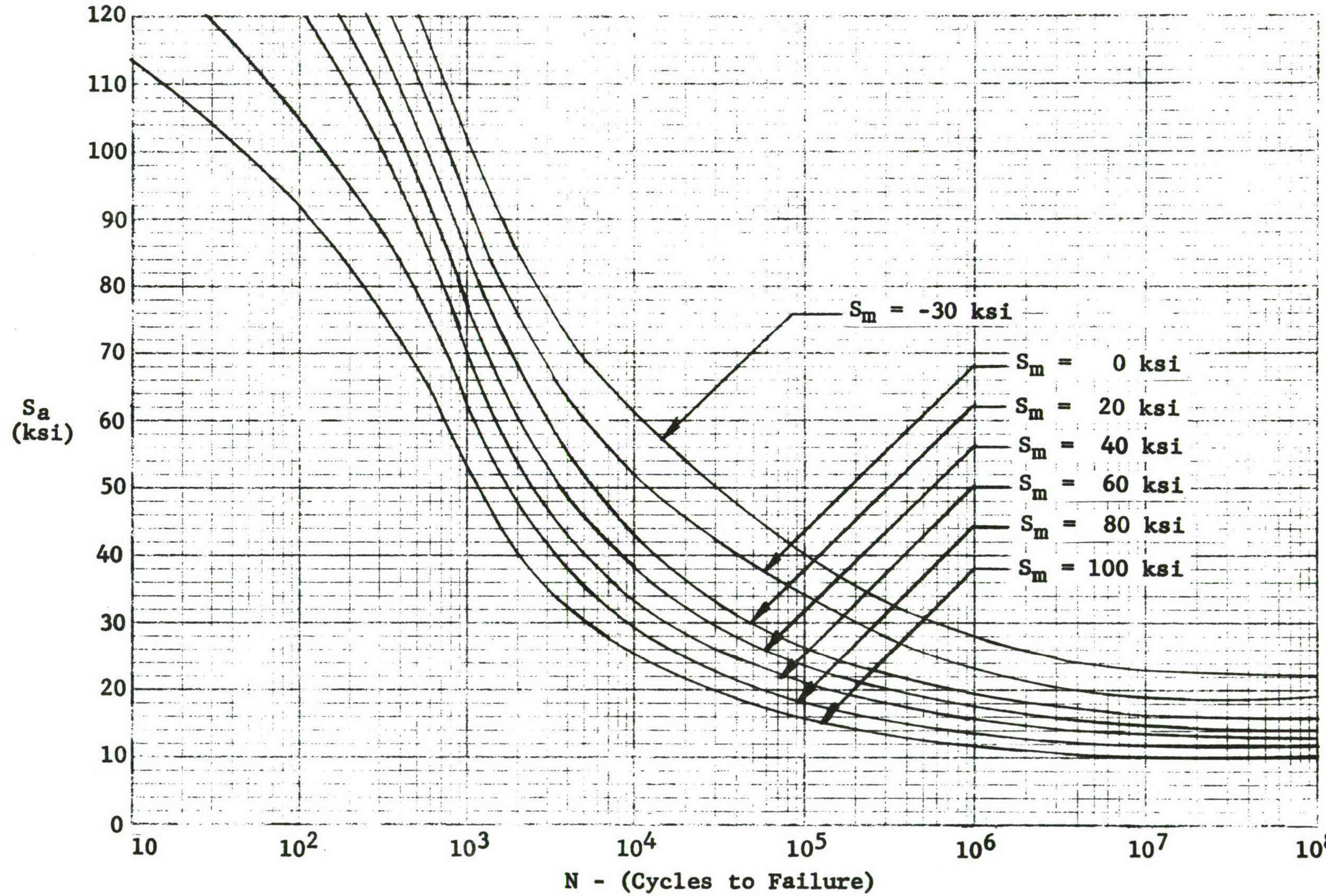


Figure 60 S-N Curves 6Al-4V Titanium Annealed Plate, K_T = 3.0

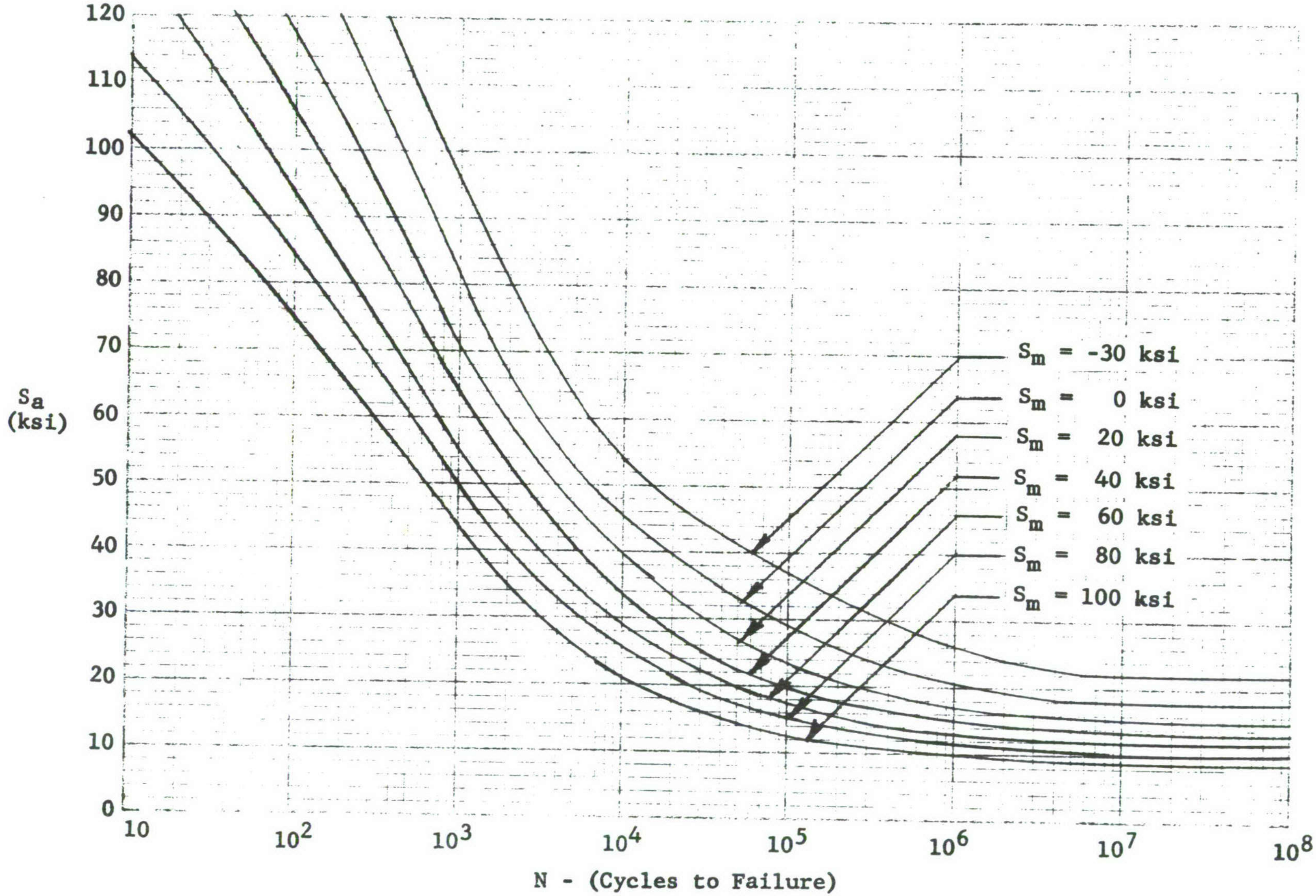


Figure 61 S-N Curves 6Al-4V Titanium Annealed Plate, K_T = 4.0

VI.2 DESIGN SERVICE LOADS SPECTRUM

The design service loads spectrum used in Phase IA was identical to the baseline fatigue spectrum with one exception. The exception is: the number of occurrences were revised to reflect the more severe exceedance data and ground-air-ground transition requirements included in MIL-A-8866A (USAF), dated 31 March 1971. (The exceedance data used in developing the baseline spectrum was that data included in a preliminary version of the MIL-A-8866A series which became available to the contractor in early 1969.)

In regards to approach, the development of the fatigue spectrum was based on a mission analysis consistent with the requirements of MIL-A-8866A. Tactical Air Command planned utilization for the baseline aircraft was used to develop 29 mission profiles and, subsequently, mission segment (flight activity) distribution. Consequently, the spectrum is a realistic interpretation of planned usage and includes all significant sources of repeated loads. The spectrum is referred to as the Mission Analysis Composite (MAC) Spectrum; its development is described in detail in contractor document FZM-12-10783, "F-111A/E/D Mission Analysis to Determine Maneuver Load Factor Exceedance Spectra," dated 27 June 1969. The Phase I and II training profiles are also included for reference in the baseline document, FZM-6100, dated 12 April 1973.

Preliminary fatigue analyses for the F-111 Fatigue Program were performed using a block type spectrum consisting of approximately 2000 individual load levels. For convenience in generating loads spectra, mission profiles were resolved into 23 usage blocks by categorizing usage time according to discrete mach-altitude-wing sweep combinations with a further proration of time within each block to the type of flight activity and to specific gross weight bands. The resulting breakdown of a typical 4000- hour service life to mach-altitude-wing sweep-mission segment combinations is shown in Table XXX.

The F-111 Recovery Program initiated the use of cyclic flaw growth analyses for establishing fleet inspection intervals. Flaw growth would ideally be calculated for every load level/ cycle in the fatigue design load spectrum. Calculations of this nature proved impractical in terms of cost and time even when computers were utilized. A certain amount of spectra simplification was required to expedite flaw growth analysis. Simplification was attained by

Table XXX
F-111F PHASE I AND II TRAINING USAGE
BUILD UP OF FLIGHT HOURS BY MISSION SEGMENT
FOR 4000 HOUR SERVICE LIFE

USAGE BLOCK	M	h	Λ	MISSION SEGMENT						TFR SEGMENT					Σ
				ASCENT	DESCENT	CRUISE	LOITER	AIR/GND	AIR/AIR	1000 M*	500 M*	200 M*	500 H*	200 H*	
1A	.6	0	16	18.49											18.49
B			26	137.23	306.28	64.68	11.40	52.84		1.8			33.68		607.91
C			50		3.20			176.68		228.60	13.66	45.54	28.23	124.77	620.68
2		10	26	13.20	74.72	43.72	26.88	12.28	27.32						198.12
3		20			39.56		2.72		18.20						60.48
4A	.75	0		73.24	18.72			2.72							94.68
B			50	5.08	16.08		5.00	287.32		22.76	37.33	135.23	42.33	111.15	662.28
5A		10	26	125.28	38.68	24.60	4.56	2.72							195.84
B			50	9.52	17.68			36.44	9.12						72.76
6A		20	26	73.60	43.28	434.80	228.56		21.84						802.08
B			50	6.60	17.00	71.48	257.44		11.84						364.36
7A		30	26		2.56	51.00	7.28								60.84
B			50		5.08		4.44		19.50						29.12
8	.9	0	72.5	4.12				61.04		21.84		21.84		26.40	135.24
9A		10	50	3.28											3.28
B			72.5	6.44											6.44
10A		20	50	1.04			.72								1.76
B			72.5	5.32		2.96			1.84						10.12
11A		30	50	1.56	.92	1.80			1.80						6.08
B			72.5	3.24			7.04		7.76						18.04
12A	1.5		50		.92	1.36	2.72								5.00
B			72.5	3.16		5.04	3.88		5.48						17.56
13	2.2	40		1.80	2.76		4.56								9.12
Σ				492.20	587.44	701.44	567.20	632.04	124.80	275.00	50.99	202.61	104.24	262.32	4000.28
% AIRPLANE LIFE				12.3	14.7	17.5	14.2	15.8	3.1	6.9	1.3	5.1	2.6	6.6	100.0

* The "M" and "H" in TFR denotes Medium ride and Hard ride.

reducing the initial 23 usage blocks to 9 usage blocks, primarily by lumping altitudes and Mach numbers. All loads were developed as balanced pitch maneuver loads. TFR, take-off and landing and gust loads spectra were included. The resulting spectra was considerably shortened while still representing 4000 hours of F-111 usage in a conservative manner. Table XXXI summarizes the nine-block usage breakdown. The spectra was arranged in 200-hour blocks and then randomly ordered using a random generator program available for use with the in-house computer. Fatigue analyses performed with the simplified spectrum produce almost identical calculated damage compared with that calculated for the original 2000 load level fatigue spectrum. An example is the wing pivot fitting fuel flow hole control point damage summarized below for a $K_T = 4.6$ and 4000 hours of usage.

- 7.33 g Fatigue Design Spectrum — $n/N = 0.325$
- 7.33 g Simplified Fatigue Design Spectrum — $n/N = 0.316$

During the F-111 Recovery Program, a flight-by-flight spectrum was developed to determine the effects of this type of spectrum ordering on flaw growth. Both the flight-by flight and the simplified block type spectra were redeveloped to reflect the more severe N_Z exceedance data in MIL-A-8866A for use in the ADP Fighter Wing Program. The flight by flight spectrum will be used almost exclusively in the follow on.

Fatigue analyses have been generated to illustrate the relatively good agreement in calculated fatigue damage when using the flight-by-flight or block spectrum approach. Typical results of this comparison are shown below for 2024-T851 aluminum S/N data and 4000 hours of baseline usage including a scatter factor of 4.0. The maximum spectrum stress used to make this comparison was 26.7 ksi.

SPECTRUM	Summation of n/N		
	$K_T = 3.0$	$K_T = 4.0$	$K_T = 5.0$
FLT x FLT	0.2284	0.7424	0.9360
Random Block	0.2580	0.7920	0.9580

Table XXXI

F-111F PHASE I AND II TRAINING USAGE

- TWENTY-NINE (29) MISSIONS FOR PHASE I AND PHASE II TRAINING
- DEFINED IN TERMS OF NINE (9) USAGE BLOCKS AS FOLLOWS:

BLOCK DESCRIPTION			BLOCK FLIGHT HOURS	MANEUVER SPECTRUM FLT. HOURS	TFR SPECTRUM FLT. HOURS
M	h	Λ			
0.6	0	26	884.7	849.2	35.5
0.75	0	26	290.5	290.5	-
0.6	0	50	620.7	179.9	440.8
0.75	0	50	735.2	386.3	348.9
0.9	0	72.5	180.9	110.8	70.1
1.5	30,000	72.5	22.5	22.5	-
2.2	40,000	72.5	9.1	9.1	-
0.75	20,000	26	862.9	862.9	-
0.75	20,000	50	393.5	393.5	-
			$\Sigma = 4000$	$\Sigma = 3104.7$	$\Sigma = 895.3$

CYCLIC LOAD SPECTRUM

- 200 HOUR BLOCKS
- LOAD RANGE (MAX. - MIN.)
- LOAD RATIO (MIN. / MAX.)
- FREQUENCY
- RANDOM OCCURRENCES
- TEMPERATURE

Comparisons showing the agreement between the spectra approaches on a flaw growth basis are presented in paragraph 7.2.1 of this report.

The good agreement obtained from comparisons of flight-by-flight versus block spectra has substantiated the use of the block spectrum approach for performing fatigue and flaw growth analyses in Phase IA. The wing pivot bending moment spectrum utilized in Phase IA is tabulated for reference in Tables XXXII through XXXVIII.

Table XXXII
SPECTRUM OF OCCURRENCES OF POSITIVE NORMAL LOAD FACTOR

					NORMAL LOAD FACTOR												
COND. NO.	Λ	M	$h \times 10^{-3}$	TIME (HRS) *	1.5	2.0	2.57	3.3	4.03	4.76	5.5	6.23	6.96	7.7	8.43	9.16	9.9
1	26	0.6	SL	849.2	20,417	13,728	13,640	10,853	3906	2080	307	82	24				
2	26	0.75	SL	290.5	6867	2598	1500	611	268	99	32	8	2				
3	50	0.6	SL	179.9	8874	7629	10,102	8319	5570	2951	1025	353					
4	50	0.75	SL	386.3	18,117	15,269	19,772	16,193	10,664	5597	1945	518	132	22	3		
5	72.5	0.9	SL	110.8	5231	4000	4773	3864	2753	1057	373	95	22	5	1		
6	72.5	1.5	30	22.5	934	660	648	513	261	114	58						
7	72.5	2.2	40	9.1	203	100	68	23	6	1							
8	26	0.75	20	862.9	16,992	9277	7051	3606	1488	752							
9	50	0.75	20	393.5	11,503	6961	5818	4707	734	402							
			$\Sigma =$	3104.7													

* TFR Hours not included.

Table XXXIII

F-111A WING PIVOT BENDING MOMENT CYCLIC MEANS & AMPS

COND. NO.	Λ	M	$h \times 10^{-3}$	ITEM (BM 26%)	NORMAL LOAD FACTOR 1.5	2.0	2.57	3.3	4.03	4.76	5.5	6.23	6.96	7.7	8.43	9.16
					IN-LBS X 10^{-6}											
1	26	0.6	SL	Mean	3.93	4.70	5.57	6.15	6.31	6.44	6.73	6.42	6.68			
				Amp	0.78	1.55	2.42	3.00	3.16	3.29	3.58	3.26	3.52			
2	26	0.75	SL	Mean	4.07	4.92	5.72	6.88	7.82	8.47	8.87	8.95	9.05			
				Amp	0.94	1.79	2.59	3.75	4.69	5.34	5.74	5.82	5.92			
3	50	0.6	SL	Mean	3.78	4.31	4.60	4.82	4.98	5.24	4.87	5.04				
				Amp	1.02	1.55	1.84	2.06	2.22	2.49	2.14	2.30				
4	50	0.75	SL	Mean	3.49	4.14	4.93	5.83	6.43	6.72	6.82	7.00	7.23	7.55	7.94	
				Amp	0.71	1.36	2.15	3.05	3.65	3.94	4.04	4.21	4.45	4.76	5.15	
5	72.5	0.9	SL	Mean	2.04	2.54	3.10	3.87	4.76	5.61	6.46	7.18	7.76	8.23	8.55	
				Amp	0.47	0.97	1.53	2.30	3.19	4.04	4.87	5.61	6.19	6.67	7.00	
6	72.5	1.5	30	Mean	2.75	3.27	3.95	4.68	5.42	6.18	6.42					
				Amp	0.56	1.08	1.76	2.49	3.23	3.99	4.23					
7	72.5	2.2	40	Mean	2.79	3.34	4.01	4.73	8.55	5.26						
				Amp	0.62	1.17	1.84	2.56	3.19	3.08						
8	26	0.75	20	Mean	3.74	4.30	4.97	5.06	5.33	5.37						
				Amp	0.56	1.12	1.79	1.88	2.15	2.19						
9	50	0.75	20	Mean	3.09	3.49	3.87	4.09	4.48	4.65						
				Amp	0.36	0.76	1.14	1.36	1.75	1.92						

Table XXXIV

SPECTRUM OF OCCURRENCES OF NEGATIVE NORMAL LOAD FACTOR

					NORMAL LOAD FACTOR								
COND. NO.	Λ	M	h	TIME (HRS) *	0.6	0.3	0	- 0.3	- 0.6	- 0.9	- 1.2	- 1.5	- 1.8
1	26	0.6	SL	849.2	10,522	1617	258	85	30	17	9	4	1
2	26	0.75	SL	290.5	256	33	5						
3	50	0.6	SL	179.9	8 304	1078	133	20	4	2			
4	50	0.75	SL	386.3	16,639	2219	285	48	13	6	3		
5	72.5	0.9	SL	110.8	4 647	678	98	22	9	5	1	1	
6	72.5	1.5	30	22.5	855	147	25	7	3	2	2		
7	72.5	2.2	40	9.1	0								
8	26	0.75	20	862.9	3 407	585	100	28	14	8	4	2	
9	50	0.75	20	393.5	4 905	843	145	41	19	12	6	3	
			Σ =	3104.7									

* TFR hours not included.

Table XXXV

F-111A WING PIVOT BENDING MOMENT CYCLIC MEANS & AMPS

COND. NO.	Λ	M	$h \times 10^{-3}$	ITEM ($BM_{26\%}$)	NORMAL LOAD FACTOR 0.6	0.3	0	-0.3	-0.6	-0.9	-1.2	-1.5	-1.8
1	26	0.6	SL	Mean	2.53	2.06	1.59	1.24	0.85	0.47	0.09	0.06	-0.03
				Amp	-0.62	-1.09	-1.56	-1.91	-2.30	-2.68	-3.07	-3.12	-3.21
2	26	0.75	SL	Mean	2.51	2.05	1.59						
				Amp	-0.62	-1.09	-1.55						
3	50	0.6	SL	Mean	2.25	1.86	1.48	1.07	0.61	0.17			
				Amp	-0.51	-0.90	-1.28	-1.69	-2.14	-2.58			
4	50	0.75	SL	Mean	2.28	1.91	1.54	1.15	0.72	0.26	-0.21		
				Amp	-0.50	-0.87	-1.24	-1.63	-2.07	-2.53	-2.99		
5	72.5	0.9	SL	Mean	1.21	0.94	0.67	0.31	-0.05	-0.16	-0.54	-0.39	
				Amp	-0.36	-0.62	-0.89	-1.25	-1.62	-2.03	-2.42	-2.27	
6	72.5	1.5	30	Mean	1.77	1.46	1.15	0.69	0.40	0.06	0.44		
				Amp	-0.42	-0.73	-1.04	-1.50	-1.79	-2.12	-1.74		
7	72.5	2.2	40	Mean	--								
				Amp	--								
8	26	0.75	20	Mean	2.55	2.07	1.60	1.24	0.85	0.47	0.13	-0.14	
				Amp	-0.63	-1.11	- 1.58	-1.94	-2.33	-2.71	-3.05	-3.32	
9	50	0.75	20	Mean	2.21	1.82	1.43	1.02	0.56	0.16	-0.20	-0.29	
				Amp	-0.52	-0.91	-1.30	-1.71	-2.17	-2.57	-2.93	-3.02	

Table XXXVI
TFR SPECTRUM OF WING PIVOT BENDING MOMENT

COND. NO.	Λ	M	$h \times 10^{-3}$	TIME (HRS)	ITEM	NORMAL LOAD FACTOR 1.5	2.0	2.5	3.0
TFR 1 (H)	26	0.6	SL	33.7	Mean	2.35	3.30	3.93	4.38
					Amp	2.33	3.27	3.90	4.36
					N	5998	1264	377	448
TFR 2 (M)	26	0.6	SL	1.8	Mean	3.06	4.00	4.63	5.09
					Amp	1.62	2.57	3.20	3.65
					N	123	12	2	4
TFR 3 (H)	50	0.75	SL	153.5	Mean	2.20	2.95	3.61	4.26
					Amp	1.90	2.64	3.30	3.95
					N	27,518	7250	2218	2040
TFR 4 (H)	50	0.6	SL	153.0	Mean	2.20	2.80	3.27	3.51
					Amp	2.01	2.61	3.08	3.31
					N	27,484	7422	2275	2035
TFR 5 (M)	50	0.75	SL	195.4	Mean	2.81	3.56	4.21	4.86
					Amp	1.29	2.04	2.69	3.35
					N	30,929	6029	1276	391
TFR 6 (M)	50	0.6	SL	287.8	Mean	2.82	3.42	3.89	4.12
					Amp	1.39	1.99	2.46	2.69
					N	25,603	3564	701	576
TFR 7 (H)	72.5	0.9	SL	26.4	Mean	1.15	1.63	2.13	2.64
					Amp	1.37	1.85	2.35	2.86
					N	4754	1347	415	351
TFR 8 (M)	72.5	0.9	SL	43.7	Mean	1.58	2.06	2.56	3.07
					Amp	0.94	1.42	1.92	2.43
					N	5308	922	192	87
			$\Sigma =$	895.3					

NOTE:

1. Means and amplitudes are given in in-lbs $\times 10^{-6}$.
2. N = number of occurrences.

Table XXXVII

TAKEOFF & LANDING SPECTRUM OF WING PIVOT BENDING MOMENT

COND. NO.	Λ	V (KNOTS)	$h \times 10^{-3}$	GW $LBS \times 10^{-3}$	ITEM	NORMAL LOAD FACTOR 1.5	2.0	2.5	3.0	3.5	4.0
T/O COND 1	26	250	SL	55	Mean	4.63	5.31	5.97	6.66	--	--
					Amp	0.67	1.34	2.01	2.70	--	--
					N	902	171	35	8	--	--
T/O COND 2	26	250	SL	62	Mean	5.17	5.96	6.72	7.38	--	--
					Amp	0.88	1.67	2.43	3.08	--	--
					N	1030	195	40	9	--	--
T/O COND 3	16	250	SL	77	Mean	5.71	6.61	7.44	8.14	--	--
					Amp	0.99	1.88	2.71	3.41	--	--
					N	709	134	28	6	--	--
T/O COND 4	16	250	SL	84	Mean	5.79	6.70	7.47	8.10	--	--
					Amp	1.01	1.91	2.68	3.31	--	--
					N	1159	220	45	10	--	--
LNDG. COND 1	26	205	SL	55	Mean	4.34	4.96	5.49	5.96	6.19	6.32
					Amp	0.69	1.31	1.84	2.30	2.54	2.67
					N	4232	1139	353	125	76	43
LNDG. COND 2	26	210	SL	58	Mean	4.62	5.28	5.87	6.34	6.59	6.73
					Amp	0.73	1.39	1.98	2.45	2.71	2.85
					N	925	249	77	27	17	9
LNDG. COND 3	26	217	SL	62	Mean	4.95	5.67	6.31	6.82	7.10	7.25
					Amp	0.77	1.49	2.14	2.64	2.92	3.08
					N	2643	711	220	78	47	27

NOTE: 1. Means and amplitudes are given in in-lbs $\times 10^{-6}$.
2. N = number of occurrences.

Table XXXVIII
GROUND-AIR-GROUND SPECTRUM OF WING PIVOT
BENDING MOMENT

BM (MEAN)	BM (AMP)	NO. OF OCCURRENCES
MILLIONS OF IN-LBS		
6.89	7.25	35
6.13	6.50	122
5.28	5.65	1046
3.51	3.88	382

Σ = 1585 = SORTIE COUNT PER 4000 HOUR SERVICE LIFE

VI.3 DEEP FLAW MAGNIFICATION FACTOR (M_K) EFFECTS

Calculations of critical flaw size (a_c) for part-through surface flaws include a deep flaw magnification factor, M_K, sometimes called the back face correction factor. The purpose of the M_K term is to account for the accelerated growth of a deep, part-through surface flaw as it approaches the back face of a finite thickness (t) sheet or plate. As with some other correction factors, several variations are available. The M_K factors used in this report are those found in the AFFDL "CRACKS" computer program listing. The value of M_K in this listing ranges from 1.0 at $(a/t) = 0$ to 1.10 at $(a/t) = 1.0$ for a flaw with $a/2c = 0.5$. Another M_K curve which has been used at Convair Aerospace is based on Boeing data. Its value ranges from 1.0 at $(a/t) = 0$ to 1.46 at $(a/t) = 1.0$. The original Boeing curve has been somewhat simplified to facilitate use in a digital computer. See Figure 62 for comparison of the curves. As can be seen, only minor variation exists in the range of (a/t) from 0 to 0.9. It is in the 0.9 to 1.0 range that significant differences occur. The primary reason for the rapid increase in the Convair M_K curve between 0.9 and 1.0 is to provide compatibility at the back face between critical flaw sizes (a_c) computed as part-through cracks and critical flaw sizes ($2c_c$) computed as through cracks. The $M_K = 1.46$ accomplishes this goal for $a/2c = 0.5$. Figure 63 displays the through and part-through critical flaw sizes for 2024-T851 plate, $\sigma_y = 57$ ksi, $t = 0.611$ in., $a/2c = 0.5$, and $K_{IC} = 28$ ksi$\sqrt{\text{in.}}$ for a range of stress from 16 to 36 ksi. The discontinuity in the curve using the AFFDL M_K is apparent compared to the relatively smooth transition from part-through to through flaw using the Convair M_K. The Convair M_K curve yields smaller critical flaw sizes in the range of (a/t) from 0.9 to 1.0 and consequently predicts shorter (more conservative) times to unstable crack growth. The stress intensity equation used to calculate part-through critical flaw size (a_c) is also used to calculate ΔK for use in flaw growth equations. Here again the Convair M_K curve provides a measure of conservatism by yielding higher ΔK values in the (a/t) range of 0.9 to 1.0 and consequently, slightly faster calculated flaw growth rates. See Figure 64 for a typical case.

The unreasonable feature connected with using the AFFDL M_K curve is that for a large range of stresses, i.e., 19.6 to 26.0 ksi in Figure 63, the critical crack size is a constant value while the basic stress intensity relationship indicates that the flaw size should vary with the square of the stress.

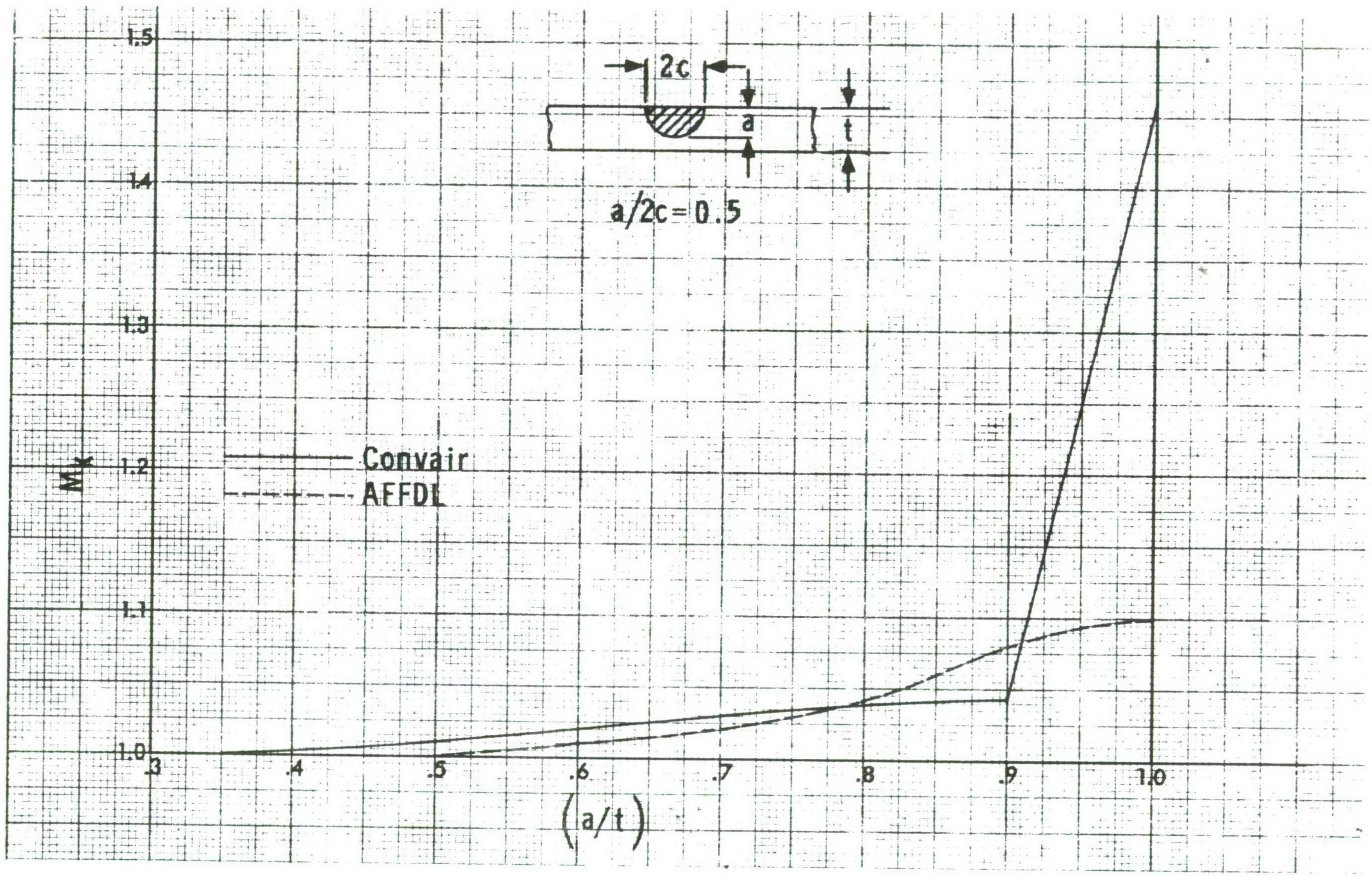


Figure 62 Comparison of Deep Flaw Magnification Factors (M_k)

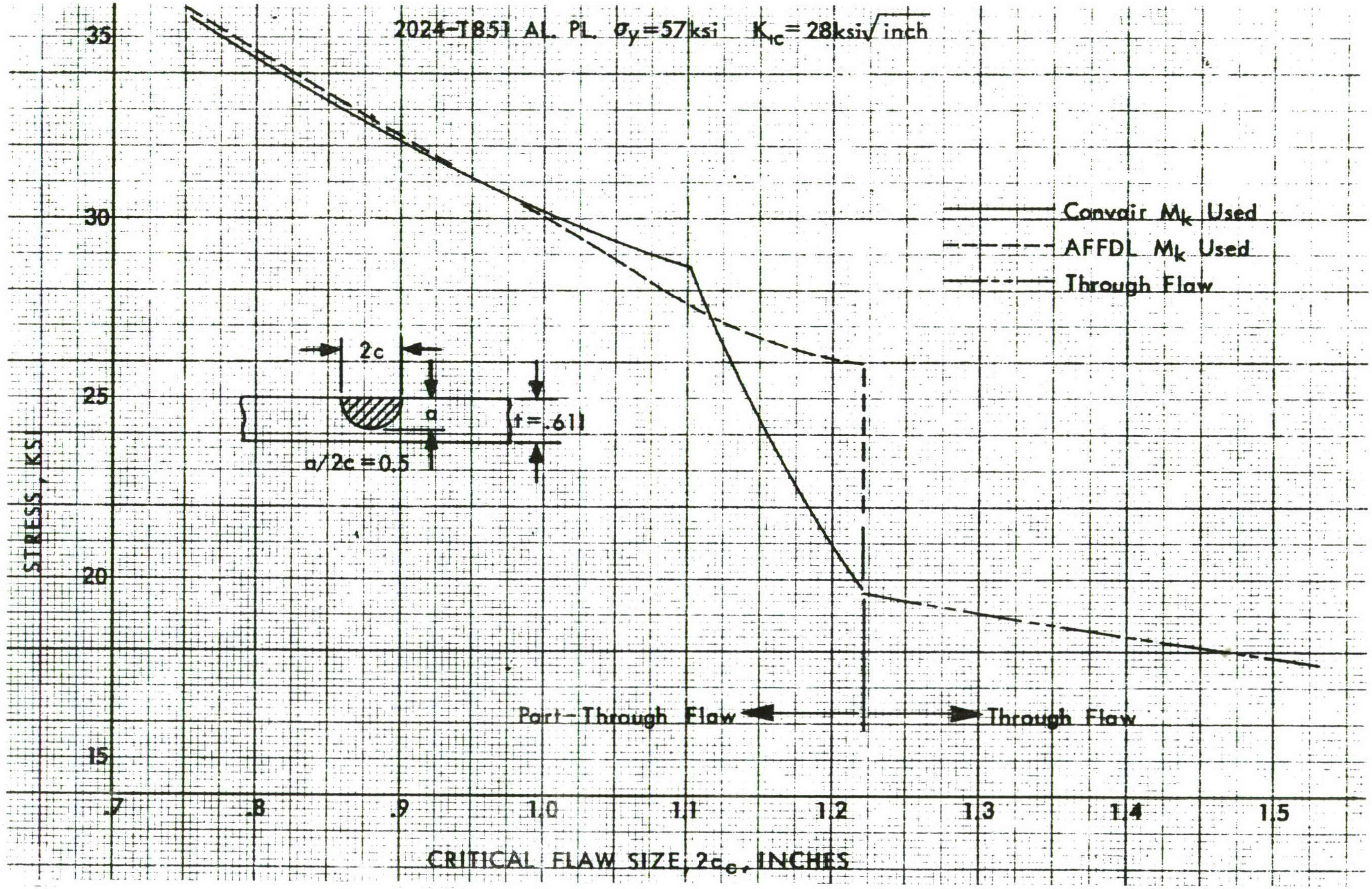


Figure 63 Comparison of Critical Flaw Sizes

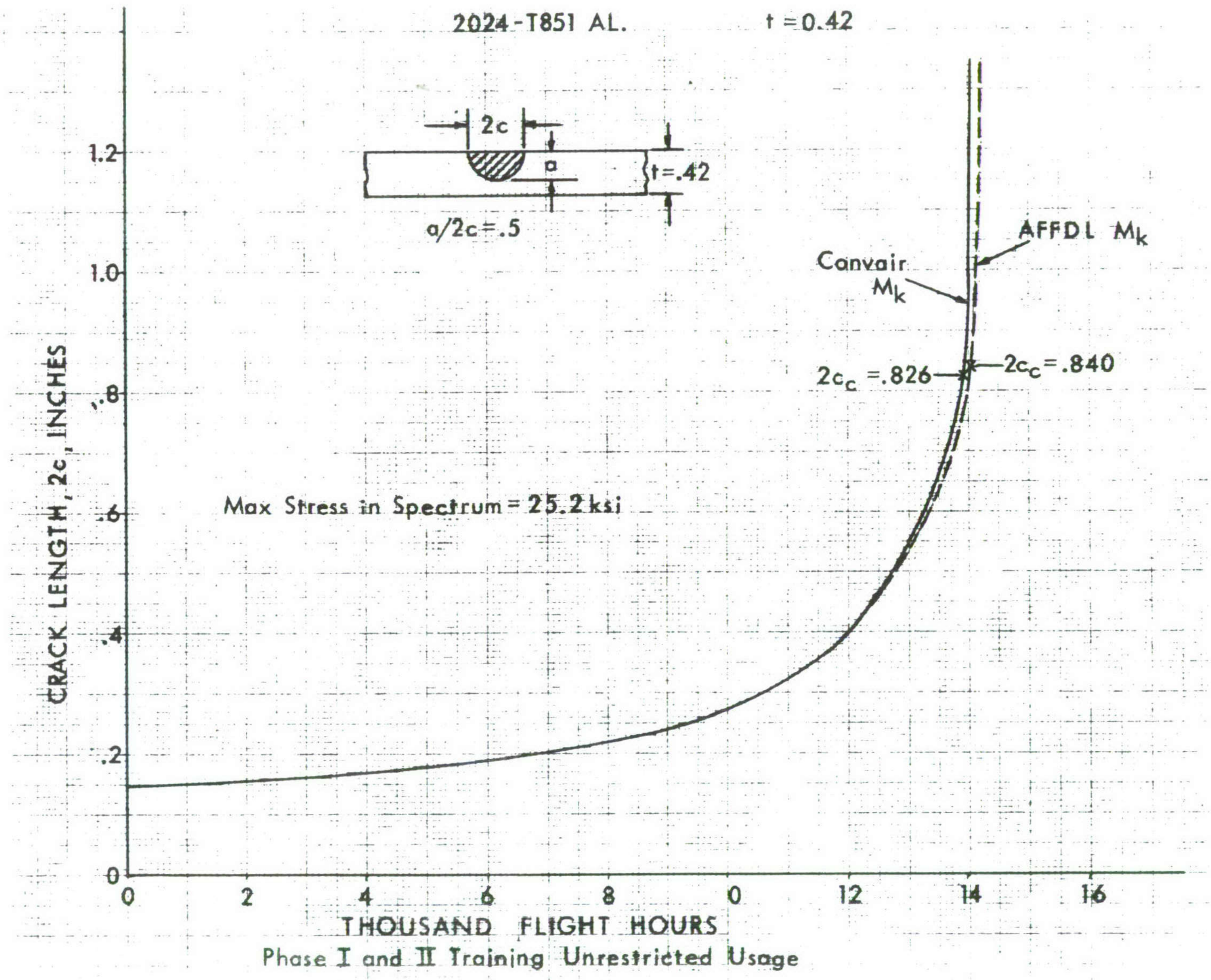


Figure 64 Surface Flaw Crack Growth Curve Effects of M_k Variation

Because of the above considerations, it is therefore recommended that the Convair M_K curve be used in the follow-on detail design effort.

VI.4 COMPARISON OF CRACKS AND TD9 FLAW GROWTH COMPUTER PROGRAMS

Flaw growth calculations in Phase IA were made using an IBM 370 computer program identified as TD9. This program produces results that are essentially identical to those produced by the AFFDL-TR-70-107 CRACKS program. TD9 was used because it has been found to be faster. The difference in run time seems to result from the relatively slow Runge Kutta integration procedure used in CRACKS. Although some form of numerical integration is the more exact method of summing the calculated crack growth increments, extensive studies have shown that approximation techniques can be used which produce slightly conservative but more rapid results. TD9 utilizes such an approximation technique. A copy of the TD9 program listing and customer instructions are provided for information in pages 164 through 214. If desired, the program will be made compatible for customer use in the follow-on. A card deck for the TD9 program has already been supplied to AFFDL under separate cover at their request.

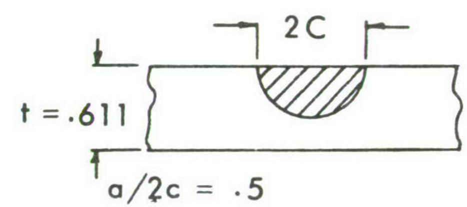
A flight-by-flight spectrum flaw growth calculation comparison was made using TD9 and a version of CRACKS available at Convair Aerospace on the CDC 6600 which includes the Wheeler retardation procedure. The runs were compared for a part-through surface cracks in the baseline (2024-T851 aluminum) lower wing skin. Results are shown in Table XXXIX. To conserve computer time, the comparative runs were terminated after 10,000 flight hours. The initial crack size was 0.075 inches by 0.150 inches.

The run times as charged, using Convair Aerospace user charge rates, was one minute for TD9 and 7.5 minutes for CRACKS.

Table XXXIX
CRACK GROWTH COMPARISON
CRACKS VS. TD9

Block No.	Calculated Crack Length, 2c, In. @ The End of Each Indicated Block	
	Convair Aerospace Program	AFFDL Program Cracks
0	0.15000	0.15000
5	0.15437	0.15402
10	0.15899	0.15830
20	0.16952	0.16794
30	0.18220	0.17930
40	0.19806	0.19302
50	0.21869	0.21016

BASELINE SURFACE FLAW IN LWR WING SKIN



2024-T851 Al.
m = 1.6

TD9 COMPUTER PROGRAM LISTING

```
       COMMON SMININ(1000),SMAXIN(1000),CYCIN(1000),COND(1000),INDEX(10),
      1SMULT(10),NLARS(10),SMIN(1000),SMAX(1000),CYC(1000),DELS(1000),TWO
      2A(10),TABA(3000,14),TABB(14,6),MOVER,NCOND,MSETS,XCYC,T,AOB,FYS,KC
      3,KIC,SF,PHISQ,EXM(14),NTWOA,JCNT,ALFA,C,J,IPASS,CRACK,DELK,SRATIO,
      4WIDTH,BOT,ETA,DADN,ICHK,LIO,KEY1,KEY2,KEY3,KEY4,KEY5,KEY6,KEY7,K12
       COMMON K13,K17,ISEG(1000),RATEN(1000),AM(11),HUM,K14,K15,IPROB,RR(
      11000),K8,K9,K16,DEK(10,20),DEDN(10,20),MD1,MD2,MD3,MD4,MD5,MD6,MD7
      2,MD8,MD9,MD(10),IMD,NRTD,DDDA,DUM1,E1,ARY1,DUM3,ARY2,AK1,RY1,RY2,K
      3A9,KEY,K10,DRY,WET,JWD,KCC,INDX,ICYC,ITWOA,CYCTD,TIMTD,INX,AREF,GM
      4AX,GMIN,PTITLE(3,16),LTITLE(2,16),LJOB,LDECK,IJOB,IDECK,K11,IERR,I
      5S(12),STMAX,STMIN,NRD,NSTCDS,XFACT,IQ(1000),NA
       DIMENSION CLS(3000)
       DIMENSION NSEG(3),DACON(3,3),DSLOPE(3,3),DKMAX(3,3),RVAL(3),DADNID
      1(10)
C
C     THIS IS THE MAIN PROGRAM. IT'S USE REQUIRES THE SUBROUTINES
C     SEQUENCE,DELTAK, CRATE, AFIT, COMPKL, OUTPUT, RPLAST, CRKGRO,
C     FINLDS, AND RLOADS.
C
      REAL KC,KIC
      INTEGER SF
      CALL GSTART (3HTR9 ,MOVER)
      REWIND 9
      GO TO (10,30), MOVER
10    CALL LIB
C     THE FIRST CARD OF EACH DECK IS READ AND CHECKED TO IDENTIFY
C     DECK AS PROBLEM OR LIBRARY INPUT. IF THE DECK IS A LIBRARY
      DECK RLOADS IS CALLED AND THE DATA IN THE DECK IS STORED  ON
      DISK UNIT 9. IF THE DECK IS A PROBLEM DECK ALL PROBLEM DATA
      IS READ IN.
C
      READ (5,1290) (PTITLE(1,I),I=1,16)
      CALL STATUS (IS)
      WRITE (6,990) IS(2),IS(3)
      IF (IS(2).EQ.2) GO TO 20
      CALL RLOADS
      GO TO 10
20    END FILE 9
      BACKSPACE 5
      ALFA=3.14159265/2.0
      C=1.0/1.21
30    CALL PROB
      REWIND 9
C
C     THREE CARDS ARE READ CONTAINING PROBLEM IDENTIFICATION. COLUMNS
C     1-60 OF THESE CARDS CAN BE USED AS CUSTOMER CHOOSES.
C
      READ (5,1290) ((PTITLE(I,K),K=1,16),I=1,3)
      CALL STATUS (IS)
      KHR=IS(8)/360000.
      ISM=IS(8)-(KHR*360000.)
      KMN=ISM/6000.
      SEC=(ISM-(KMN*6000.))/100.

      THE FOLLOWING OPTION CARD PERMITS THE USER TO (1) EITHER
C     HAVE A FINITE WIDTH PLATE (KEY1=0) OR AN INFINITE PLATE
```

```
C      (KEY1=1), (2) EITHER INPUT UP TO 10 INITIAL CRACK LENGTHS
C      (KEY2=0) OR HAVE SUBROUTINE CHOOSE DO IT (KEY2=1), (3)
       INTERPRET LIBRARY DATA AS EITHER MEAN AND ALTERNATING
       STRESSES (KEY3=1) OR MINIMUM AND MAXIMUM STRESSES (KEY3=0),
       (4) CHOOSE ONE OF SEVERAL SEQUENCING OPERATIONS TO BE
       PERFORMED ON THE SPECTRUM (KEY4=0,1,2,3), (5) EITHER
       WRITE (6,980) KHR,KMN,SEC
C      PRINT (KEY5=0) OR SKIP (KEY5=1) THE CRACK GROWTH FOR
C      INDIVIDUAL LAYERS ON EACH PASS, (6) USE A VARIABLE
C      CORRECTION FACTOR M (KEY6=0),OR READ IN M VALUES (KEY6=1),OR
C      BOEING M VALUES FOR A/2C=.5 USED (KEY6=2); LAB AIR AND/OR JP4
C      (KEY7=0),OR HIGH HUMIDITY AND/OR JP4 (KEY7=1),OR LAB AIR AND/OR
C      DISTILLED WATER (KEY7=2),OR HIGH HUMIDITY AND/OR DISTILLED WATER
C      (KEY7=3); ONE ENVIRONMENT WILL BE USED (K8=0),PERCENTAGES OF WET
C      AND DRY ENVIRONMENT DATA USED (K8=1), PERCENTAGES OF WET,DRY,AND
C      HUMIDITY DATA USED (K8=2); DADN VS DELTAK DATA TO BE
C      READ IN FOR 3 STRESS RATIOS  AND 3 CYCLIC RATES (9 SETS)
C      (K9=2) OR DADN VS DELTAK DATA READ IN FOR 3 STRESS RATIOS OF
C      DRY DATA (K9=1),OR HUMIDITY DATA USED (K9=3), OR JP4 OR DISTILLED
C      WATER HUMIDITY DATA USED (K9=4); DATA WILL BE READ
C      READ FOR CRACK INIATING IN A HOLE (K10=1) OR NORMAL PROCEDURE
C      FOR CRACK IN A PLATE (K10=0), STRESS GRADIANT WILL BE USED FOR
C      STRESS VARRYING WITH CRACK DEPTH(K11=1) OR CONSTANT STRESS
C      ARE REPEATED YY TIMES EACH PASS (K12=1), LOADS SPECTUM USED AS
C      ENTERED (K12=0); PRINTED OUTPUT (K13=1), MICROFILM OUTPUT (K13=2),
C      PRINTED AND MICROFILM OUTPUT (K13=3); THE LAST PORTION OF LOADS
C      SPECTRUM IS DIVIDED SUCH THAT SOME LOAD ARE USED IN PASS 1 OTHERS
       IN PASS 2 ETC. THRU PASS 4,THEN PASS 5 IS SAME AS 1 (K14=1),
       SPECTRUM USED AS INPUT (K14=0);  PLOTTED OUTPUT GIVEN (K15=1),
       APPLIED (K11=0); THE FIRST XX LOAD LEVELS IN THE LOADS SPECTRUM
       NO PLOTTED OUTPUT (K15=0).
C
       READ (5,1010) KEY1,KEY2,KEY3,KEY4,KEY5,KEY6,KEY7,K8,K9,K10,K11,K12
      1,K13,K14, K15,K16,K17,K18
       IF (K13.LT.1.OR.K13.GT.3) K13=1
       CALL XCOPY (K13)
       WRITE (6,1000) ((PTITLE(I,K),K=1,16),I=1,3)
C
       KA9=K9
       IF (K9.EQ.0) KA9=3
C      THE JOB AND DECK NUMBER OF LIBRARY TO BE USED , THICKNESS,
C      WIDTH, STRESS MAX AND MIN FACTORS(TO BE USED WITH STRESS GRADIANT)
C      ARE ENTERED ON NEXT CARD
C
       READ (5,1100) LJOB,LDECK,T,TWOA(1),STMAX,STMIN,WIDTH
       IF (K11.EQ.1.AND.STMAX.LT.0.001) GO TO 250
C      A/B RATIO , PHI SQUARED, DRY AND WET FACTORS(TO BE USED WHEN
C      ENVIRNMENT VARRIES), E1 (RETARDATION EXPONENT), AND NRTD (NRTD=2
C      FOR BOTH RETARDED AND NON RETARDED , NRTD=1 FOR NON RETARDED, AND
C      NRTD =0 FOR RETARDED) ARE ENTERED ON NEXT CARD
       READ (5,1070) AOB,PHISQ,DRY,WET,HUM,NRD
C
       IF (K8.EQ.1.AND.DRY.LT.0.001) GO TO 260
       TENSILE YIELD STRENGTH, KC, KIC, AND THRESHOLD VALUES ARE INPUT
       READ (5,1020) FYS,KC,KIC,CYCTD,TIMTD,BLK
       NEXT READ A CYCLIC MULTIPLIER AND THE NUMBER OF PASSES
```

```
      READ (5,1050) XCYC,SF,LIO,IPROB,M2,M3,M4,RESID1,RESID2,JOB

      THE NUMBER (NTWOA) AND VALUES (TWOA(I)) OF THE INITIAL
      CRACK LENGTHS ARE NOW READ.

      JOE=100
C
C
C     THE NUMBER OF SPECTRUM MULTIPLIER SETS IS READ IN
C
      READ (5,1030) MSETS, NPAS, ILR, DIA, FACDA , FMAX
      IF (FMAX.LE.1.0) FMAX=3.4
      IF (FACDA.LT.0.01) FACDA=1.0
C
      IF (KEY2.EQ.1) READ (5,1060) SMAX(1000)
      IF (K9.NE.2) GO TO 80
C     READ IN DA/DN VS DELTA K CURVES FOR MULTIPLE R VALUES
      READ (5,1080) MD1,MD2,MD3,MD4,MD5,MD6,MD7,MD8,MD9
      READ (5,1090) ((DEDN(I,M),M=1,10),(DEK(I,M),M=1,10),I=1,9)
      MD(1)=MD1
      MD(2)=MD2
      MD(3)=MD3
      MD(4)=MD4
      MD(5)=MD5
      MD(6)=MD6
      MD(7)=MD7
      MD(8)=MD8
      MD(9)=MD9
      DO 50 I=1,9
      M=MD(I)
      DO 40 MT=2,M
      M1=MT-1
      IF (DEDN(I,M1).GE.DEDN(I,MT).OR.DEK(I,M1).GE.DEK(I,MT)) GO TO 60
40    CONTINUE
50    CONTINUE
      GO TO 70
60    WRITE (6,880) I,M1,MT
      CALL ERROR (242)
      GO TO 30
70    CONTINUE
80    CONTINUE
      INDX=0
      DUM3=1.0/(6.0*3.1416*FYS*FYS)
      IF (K18.EQ.1) DUM3 =DUM3 *3.
      GMIN=1.0
      GMAX=1.0
      AREF=1.0
      KDUM=2
      NSTCDS=1
C     READ GMAX,GMIN,AND AREF FOR CRACK IN A HOLE(K10=1)
      IF (K10.EQ.1) READ (5,1020) GMAX,GMIN,AREF
C     CALL FINLDS AND READ THE APPROPRIATE LOADS LIBRARY FROM DISK
C     UNIT 9 INTO CORE STORAGE
      CALL FINLDS
      IF (IERR.EQ.0) GO TO 90
      WRITE (6,960) IERR
```

```
      CALL SKIPPR
      GO TO 30
90    CONTINUE
      WRITE PROBLEM INPUT
      WRITE (6,1000) ((LTITLE(I,K),K=1,16),I=1,2)
      WRITE (6,820) KEY1,KEY2,KEY3,KEY4,KEY5,KEY6,KEY7,K8,K9,K10,K11,K12
     1,K13, K14,K15,K16,K17,K18
      IF (KEY1.EQ.0) GO TO 100
      WRITE (6,1270) T
      GO TO 110
100   WRITE (6,1280) T,WIDTH
110   WRITE (6,1130) ADB,PHISQ,FYS,KC,KIC,CYCTD,TIMTD,SF,JCNT
      WRITE (6,830) LJOB,LDECK,STMAX,STMIN,DRY,WET,NRD,XCYC,MSETS
      IF (K8.EQ.2) WRITE (6,810) HUM
      WRITE (6,840) RESID1,RESID2,TWOA(1)
      IF (K10.EQ.2) WRITE (6,1450) DIA
      WRITE (6,1460) FACDA
      WRITE (6,1340)
      IF (KA9.EQ.5) GO TO 88
      IF (K8.NE.0.OR.K9.EQ.1) WRITE (6,1350)
      IF (K8.EQ.0.AND.K9.EQ.1)  GO TO 114
      IF (K8.EQ.0.AND.KA9.EQ.3) GO TO 112
      IF (K8.LE.1) GO TO 111
112   IF (KEY7.EQ.0.OR.KEY7.EQ.2) WRITE (6,1320)
      IF (KEY7.EQ.1.OR.KEY7.EQ.3) WRITE (6,1330)
      IF (K8.EQ.0) GO TO 114
111   IF (K9.EQ.2) GO TO 113
      IF (KEY7.LE.1) WRITE (6,940)
      IF (KEY7.GE.2) WRITE (6,950)
      GO TO 114
   88 READ (5,1400)  IPF , NRC ,(DADNID(I) ,I=1,10),(NSEG(K),K=1,NRC)
      DO 82 I=1,NRC
      READ (5,1410)  (DACON(I,J),DSLOPE(I,J),DKMAX(I,J), J=1,3),RVAL(I)
   82 CONTINUE
      IF (IPF.EQ.0) WRITE (6,1420)  (DADNID(I),I=1,10 )
      IF (IPF.EQ.1) WRITE (6,1430)  (DADNID(I),I=1,10 )
      DO 84 I=1,NRC
      K=NSEG(I)
      WRITE (6,1440) (DACON(I,J),DSLOPE(I,J),DKMAX(I,J), RVAL(I),J=1,K)
   84 CONTINUE
      GO TO 114
113   WRITE (6,1360)
114   CONTINUE
      IF (KEY2.EQ.1) WRITE (6,870) SMAX(1000)
      IF (K12.EQ.1) WRITE (6,970) NPAS,ILR
      IF (K9.EQ.2) WRITE (6,850) MD1,MD2,MD3,MD4,MD5,MD6,MD7,MD8,MD9,((D
     1EDN(I,M),M=1,10),(DEK(I,M),M=1,10),I=1,9)
      IF (K10.EQ.1) WRITE (6,860) GMAX,GMIN,AREF
      IF (K10.EQ.1.AND.GMAX.LT.0.001) GO TO 270
      JCNT=0
      DO 130 I=1,NCOND
      INDEX(I)=JCNT+NLARS(I)
      JCNT=INDEX(I)
130   CONTINUE
      IF (KEY6.NE.1) GO TO 140
      READ BOEING MK DATA WHEN (KEY6=1)
```

```
      READ (5,1110) (AM(M),M=1,11)
      IF (KEY6.EQ.1.AND.AM(1).LT.0.001) GO TO 280
      WRITE (6,1120) (AM(M),M=1,11)
140   CONTINUE
      READ (5,1040) (SMULT(M),M=1,10),E1,KR1,KR2
      READ (5,1310) (EXM(M),M=1,MSETS)
      NRTD=NRD
      DO 780 NSTCDS =1, MSETS
      L=0
      KA=1
      IF (K16.EQ.0.AND.NSTCDS.GT.1) GO TO 408
      IF (K16.EQ.0) GO TO 142
      L= NSTCDS
      KB=JCNT
      GO TO 143
  142 L=L+1
      KB=INDEX(L)
  143 CONTINUE
      DO 150 M=KA,KB
      CYC(M)=CYCIN(M)*XCYC
      SMIN(M)=(SMININ(M)*SMULT(L))+RESID1
      SMAX(M)=SMAXIN(M)*SMULT(L)
      IF (KEY3.EQ.0) SMAX(M)=SMAX(M)+RESID1
      IQ(M)=L
150   CONTINUE
      KA=KB+1
      IF (K16.EQ.0.AND.L.LT.NCOND) GO TO 142
C
      IN THE NEXT LOOP, ALTERNATING AND MEAN STRESSES ARE
      CONVERTED TO MAXIMUM AND MINIMUM STRESSES WHERE ON INPUT
      THE MINIMUM AND MEAN ARE SYNONYMOUS AS ARE MAXIMUM AND
      ALTERNATING.
C
      IF (K11.EQ.1.AND.NSTCDS.GT.1) GO TO 180
      IF (KEY3.EQ.0) GO TO 180
      DO 170 KK=1,JCNT
      DUM1=SMIN(KK)
      DUM2=SMAX(KK)
      SMIN(KK)=DUM1-DUM2
      SMAX(KK)=DUM1+DUM2
170   CONTINUE
180   CONTINUE
C     LOOP 220 PERMITS ONLY POSITIVE SPECTRUM STRESSES, INITIALIZES PART
C     IAL CYCLE COUNTER, CALCULATES STRESS RATIO AND DELTA STRESS, AND S
C     ETS SMININ AND SMAXIN FOR STRESS GRADIENT CASE.
      DO 220 KK=1,JCNT
      CLS(KK) =0.001
      CLS(KK+JCNT) =0.001
      CLS(KK+JCNT+JCNT) =0.001
      IF (SMAX(KK).GE.SMIN(KK)) GO TO 190
      DUM2=SMAX(KK)
      SMAX(KK)=SMIN(KK)
      SMIN(KK)=DUM2
190   CONTINUE
      IF (SMIN(KK).LT.0.) SMIN(KK)=0.0
      IF (SMAX(KK).LT.0.) SMAX(KK)=0.0
```

```
      IF (K11.EQ.0.OR.NSTCDS.GT.1) GO TO 200
      SMININ(KK)=SMIN(KK)
      SMAXIN(KK)=SMAX(KK)
200   CONTINUE
      DELS(KK)=SMAX(KK)-SMIN(KK)
C     COMPUTE R VALUE
      IF (SMAX(KK).EQ.0.0) GO TO 210
      RR(KK)=SMIN(KK)/SMAX(KK)
      GO TO 220
210   RR(KK)=1.0
220   CONTINUE
C
C     KEY4 IS NOW TESTED TO DETERMINE THE MANNER IN WHICH
C     THE SPECTRUM WILL BE ARRANGED. BUT FIRST, THE ARRAY
C     DELS MUST BE GENERATED BECAUSE IT WILL BE USED IN ANY
C     SEQUENCING OPERATION.
C
      IF (KEY4.EQ.1.OR.KEY4.EQ.2) CALL SEQENC
      IF (NSTCDS.GT.1.AND.K16.NE.0) GO TO 225
      IF (KEY4.EQ.3.OR.KEY4.EQ.4) CALL RANGEN (KR1,KR2)
  225 CONTINUE
C
C
C     FOR INFORMATIVE PURPOSES, THE MULTIPLIERS OF THE CYCLES
C     AND THE CONDITIONS ARE NOW PRINTED. ALSO PRINTED ARE THE
C     ARRAYS COND, SMININ, SMAXIN, CYCIN, SMIN, SMAX, CYC, AND
C     DELS.
C
      IF (NSTCDS.NE.1.AND.K16.EQ.0)  GO TO 400
      WRITE (6,1250) XCYC
      IF (KEY4.EQ.3.OR.KEY4.EQ.4) WRITE (6,1300) KR1,KR2
      WRITE (6,1260)
      JKLA=1
      DO 230 JKL=1,NCOND
      IF (K16.EQ.0) WRITE (6,1230) COND(JKLA), SMULT(JKL)
      IF (K16.NE.0) WRITE (6,1230) COND(JKLA), SMULT(NSTCDS)
      JKLA=1+INDEX(JKL)
230   CONTINUE
      GO TO 300
240   CALL SKIPPR
      GO TO 30
250   WRITE (6,890)
      GO TO 240
260   WRITE (6,900)
      GO TO 240
270   WRITE (6,910)
      GO TO 240
280   WRITE (6,920)
      GO TO 240
290   WRITE (6,930) NRTD
      GO TO 240
300   CONTINUE
C     THE ARRAYS TABA AND TABB MUST BE ZEROED BECAUSE THE
C     ZEROES ARE USED AS INDICATORS FOR THE OUTPUT FORMAT
      OF THE TABLES.
      IF (NSTCDS.NE.1.AND.K16.NE.0)  GO TO 400
```

```
C
      M21=M2-1
      M31=M3-1
      M41=M4-1
      M11=ILR+1
      DO 320 IJ=1,3000
      DO 310 IM=1,14
      TABA(IJ,IM)=0.0
310   CONTINUE
320   CONTINUE
      DO 340 IJ=1,MSETS
      DO 330 IM=1,6
      TABB(IJ,IM)=0.0
330   CONTINUE
340   CONTINUE
      IF (KEY4.EQ.3.OR.KEY4.EQ.4) GO TO 400
      WRITE (6,1140)
      IF (KEY3.EQ.0) GO TO 350
      WRITE (6,1150)
      GO TO 360
350   WRITE (6,1160)
360   CONTINUE
      KAT=45
      DO 390 II=1,JCNT
      WRITE (6,1170) COND(II),SMININ(II),SMAXIN(II),CYCIN(II),RATEN(II),
     1SMIN(II),SMAX(II),CYC(II),RATEN(II),DELS(II)
      IF (II.LT.KAT) GO TO 390
      WRITE (6,1140)
      IF (KEY3.EQ.0) GO TO 370
      WRITE (6,1150)
      GO TO 380
370   WRITE (6,1160)
380   KAT=KAT+45
390   CONTINUE
400   CONTINUE
      IF (NRTD.LT.0.OR.NRTD.GT.3) GO TO 290
      ITWOA=1
C
C     THE LOOP TO 780 GROWS CRACK FOR EACH RETARDATION FACTOR (MK)
  408 CONTINUE
      E1=EXM(NSTCDS)
      IF (KEY4.NE.3.AND.KEY4.NE.4) GO TO 410
      IF (K17.EQ.1) CALL RANGEN (KR1,KR2)
  410 CONTINUE
      IF (E1.LT.0.001) NRTD=1
      DUM1=1.0
      NA=0
      XFACT=1.0
      KNT=0
      ARY2=0.0
      ICHK=0
      KEY=0
      CRACK=TWOA(ITWOA)
      BOT=CRACK/(2.0*AOB*T)
      IF (NRTD.EQ.3) JOE=1
      IF (KEY2.EQ.0.OR.NRTD.EQ.1) GO TO 420
```

```
      J=1000
      SMIN(1000)=0.0
      CALL DELTAK
      DDDA=CRACK/(2.0*AOB)
      CALL RPLAST (DUM3,DDDA,ARY1,ARY2,AK1,E1,RY1,RY2,DUM1)
      WRITE (6,800) ARY2
420   CONTINUE
C
C     THE LOOP TO 760 REAPPLIES THE SPECTRUM AS DETERMINED BY
C     THE NUMBER OF PASSES.
C
      KPS=0
      DO 760 IPASS=1,SF
      KPS=KPS+1
      IF (KEY5.EQ.1) GO TO 430
      WRITE (6,1180) IPASS
      WRITE (6,1190)
430   INX=0
      JX=0
C
C     EACH OF THE TOTAL NUMBER OF LAYERS WITHIN THE SPECTRUM
C     IS NOW APPLIED TO THE INITIAL CRACK IN LOOP TO 730.
C
      JGX=0
440   JGX=JGX+1
      DO 730 J1J=1,JCNT
      IF (K14.NE.1) GO TO 450
      IF (KPS.EQ.2.AND.J1J.EQ.M11) J1J=M2
      IF (KPS.EQ.3.AND.J1J.EQ.M11) J1J=M3
      IF (KPS.EQ.4.AND.J1J.EQ.M11) J1J=M4
450   CONTINUE
      J=J1J
      IF (KEY4.EQ.3.OR.KEY4.EQ.4) J=ISEG(J1J)
      JWD=0
      IF (K8.EQ.0) GO TO 490
      IF (DRY.LT.0.01.AND.WET.LT.0.01) CALL ERROR (306)
      CYC(J)=CYCIN(J)*XCYC*DRY
      KA9=1
      GO TO 480
460   CYC(J)=CYCIN(J)*XCYC*WET
      KA9=4
      IF (K9.EQ.2) KA9=2
      GO TO 480
470   CYC(J)=CYCIN(J)*XCYC*HUM
      KA9=3
480   CONTINUE
      JWD=JWD+1
490   CONTINUE
      IF (NRTD.EQ.1) GO TO 540
C     IF RETARDATION IS REQUIRED , THE ANALYSIS IS DONE CYCLE BY CYCLE
      J1=J
      IF (K8.NE.0.AND.KA9.EQ.1) J1=J+JCNT
      IF (K8.NE.0.AND.KA9.EQ.3) J1=J1+(2*JCNT)
      CCYC=CYC(J)+CLS(J1)
      KCY=CCYC
      CLS(J1)=CCYC-KCY
```

```
      CCYC=KCY
      IF (KCY.GT.0) GO TO 500
      DELK=0.0
      IF (KEY5.EQ.0) CALL WRITIN (CCYC,JX,1)
      GO TO 720
500   CONTINUE
      CCYC=CCYC-JOE
      IF (CCYC) 510,510,520
510   RCY=JOE+CCYC
      GO TO 530
520   RCY=JOE
530   CONTINUE
  540 CONTINUE
      IF (K11.EQ.0) GO TO 550
      XFACT=STMAX-(BOT*(STMAX-STMIN))
      IF (BOT.GT.1.0) XFACT=STMIN
      SMIN(J)=XFACT*SMININ(J)+RESID2
      SMAX(J)=XFACT*SMAXIN(J)+RESID2
C
550   CONTINUE
      IF (K10.EQ.0) CALL DELTAK
      IF (K10.EQ.2) CALL RDELK(DIA,FMAX)
      IF (K10.NE.1) GO TO 560
      FSUBK=1.2*SQRT(3.1416*CRACK/2.0) /1.5708
      AK1= SMAX(J) * FSUBK
      DELK= (SMAX(J)-SMIN(J)) * FSUBK
      GKT=GMIN+((GMAX-GMIN)*EXP(-4.605*CRACK/(2.0*AREF)))
      DELK=DELK*GKT
      AK1 = AK1 * GKT
560   CONTINUE
C     THE FOLLOWING TESTS SHOULD BE CONSIDERED TEMPORARY UNTIL
C     SUCH TIME AS THE DA/DN VS DEL K PLOT IS BETTER DEFINED.
C
      IF (DELK.LT.CYCTD) GO TO 710
      IF (BOT.GE.1.0) GO TO 570
      IF (DELK.LT.(0.9*KIC)) GO TO 590
      IF (KEY5.EQ.1) GO TO 580
      WRITE (6,1200)
      WRITE (6,1210) J,SMIN(J),SMAX(J),CYC(J),RATEN(J),DELK
      GO TO 580
570   IF (DELK.LT.(0.9*KC)) GO TO 590
      IF (KEY5.EQ.1) GO TO 580
      WRITE (6,1240)
      WRITE (6,1210) J,SMIN(J),SMAX(J),CYC(J),RATEN(J),DELK
580   KDX=IPASS
      JDX=J1J-1
      DAA=CRACK
      GO TO 770
C
C     SUBROUTINE CRATE DEFINES A CRACK GROWTH RATE, DADN, FOR
C     A GIVEN VALUE OF DELTA K. IT THEN CALCULATES A NEW BOT
C     AND CRACK LENGTH.
C
590   CONTINUE
      IF (NRTD.EQ.1) GO TO 600
      DDDA=CRACK/(2.0*AOB)
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      CALL RPLAST (DUM3,DDDA,ARY1,ARY2,AK1,E1,RY1,RY2,DUM1)              TR90504
  600 CONTINUE                                                           TR90505
      RATE=RATEN(J)                                                      TR90506
      R1=RR(J)                                                           TR90507
      IF (KA9.EQ.2) GO TO 620                                            TR90508
      IF (KA9.EQ.4) GO TO 610                                            TR90509
      IF (KA9.EQ.5) GO TO 625                                            TR90510
      CALL CN (RATE,KA9,R1,KEY7,DADN,DELK)                               TR90511
      GO TO 630                                                          TR90512
  610 CALL COMP1 (DADN,KEY7,R1,RATE,DELK)                                TR90513
      GO TO 630                                                          TR90514
  620 CALL COMPKL (DADN,R1,RATE,DELK,DEK,DEDN,MD)                        TR90515
      GO TO 630                                                          TR90516
  625 CALL ADPDA (R1,DADN,DELK,NSEG,DACON,DSLOPE,DKMAX,RVAL,IPF,NRC)    TR90517
  630 CONTINUE                                                           TR90518
      DADN =DADN * FACDA                                                 TR90519
      IF (NRTD.EQ.1) GO TO 640                                           TR90520
      KNT1=0                                                             TR90521
      IF (DUM1.GT.0.999.OR.RCY.LE.2.0) KNT1=1                            TR90522
      CALL CRKGRO (DCRACK,CRACK,DADN,DUM1,AOB,RCY,KNT,KNT1)              TR90523
      GO TO 650                                                          TR90524
  640 CONTINUE                                                           TR90525
      DCRACK=2.0*DADN*CYC(J)*AOB                                         TR90526
      CCL=CYC(J)                                                         TR90527
      CRACK=CRACK+DCRACK                                                 TR90528
      IF (KEY5.EQ.0) CALL WRITIN (CCL,JX,2)                              TR90529
  650 CONTINUE                                                           TR90530
      BOT=CRACK/(2.0*T*AOB)                                              TR90531
      IF (NRTD.EQ.1) GO TO 670                                           TR90532
      IF (DUM1.GT.0.999.OR.RCY.LE.2.0) GO TO 660                         TR90533
      DUM=DUM1                                                           TR90534
      CALL DELTAK                                                        TR90535
      DDDA=CRACK/(2.0*AOB)                                               TR90536
      CALL RPLAST (DUM3,DDDA,ARY1,ARY2,AK1,E1,RY1,RY2,DUM1)              TR90537
      DUM4=DUM1                                                          TR90538
      DUM1=((DUM4-DUM)*0.6)+DUM                                          TR90539
      KNT1=1                                                             TR90540
      CALL CRKGRO (DCRACK,CRACK,DADN,DUM1,AOB,RCY,KNT,KNT1)              TR90541
  660 CONTINUE                                                           TR90542
      IF (KEY5.EQ.0) CALL WRITIN (RCY,JX,2)                              TR90543
      IF (CCYC.GT.0.0) GO TO 500                                         TR90544
  670 CONTINUE                                                           TR90545
      IF (KEY1.EQ.1) GO TO 690                                           TR90546
      IF (CRACK.LT.WIDTH) GO TO 690                                      TR90547
      IF (KEY5.EQ.1) GO TO 680                                           TR90548
      WRITE (6,1220)                                                     TR90549
      WRITE (6,1210) J,SMIN(J),SMAX(J),CYC(J),RATEN(J),DELK,DADN,CRACK  TR90550
  680 KDX=IPASS                                                          TR90551
      JDX=J1J                                                            TR90552
      DAA=CRACK                                                          TR90553
      GO TO 770                                                          TR90554
  690 CONTINUE                                                           TR90555
C                                                                        TR90556
C     COLUMNS 4,5,6 OF ARRAY TABB ARE USED TO STORE THE                  TR90557
      CRACK LENGTH AND PASS AND LAYER NUMBERS AT THE TIME                TR90558
      THE PART-THRU CRACK BECAME A THRU CRACK.                           TR90559
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C
      IF (KEY.EQ.1.OR.BOT.LT.1.0) GO TO 700
      TABB(NSTCDS,4)=CRACK
      IF (K10.EQ.2) TABB(NSTCDS,4) = TABB(NSTCDS,4) /(AOB*2.)
      TABB(NSTCDS,5)=IPASS
      TABB(NSTCDS,6) =J1J
      KEY=1
  700 DAA=CRACK
      GO TO 720
  710 IF (KEY5.EQ.0) CALL WRITIN (RCY,JX,3)
  720 IF (JWD.EQ.1) GO TO 460
      IF (K8.EQ.2.AND.JWD.EQ.2) GO TO 470
      IF (K12.NE.1) GO TO 730
      IF (JGX.LT.NPAS.AND.J.EQ.ILR) GO TO 440
      IF (J.EQ.M21.OR.J.EQ.M31.OR.J.EQ.M41) GO TO 740
  730 CONTINUE
  740 IF (KPS.EQ.4) KPS=0
C     THE FINAL CRACK LENGTH FOR EACH PASS IS NOW STORED IN
C     TABA.
C
      TABA(IPASS,NSTCDS)=CRACK
      IF (K10.EQ.2) TABA(IPASS,NSTCDS)=TABA(IPASS,NSTCDS)/(AOB*2.)
      IF (IPASS.GT.3) GO TO 750
      DCRACK=CRACK-TWOA(ITWOA)
      IF (DCRACK.LT.0.00001) ICHK=1
      IF (ICHK.NE.1) GO TO 750
      TWOA(ITWOA)=TWOA(ITWOA)+0.01
      IF (TWOA(ITWOA).GT.0.5) GO TO 790
      GO TO 410
  750 CONTINUE
  760 CONTINUE
C
C     COLUMN 2 OF TABB IS USED AS AN INDEX FOR PRINTING. THE
C     MAGNITUDE OF THE COEFFICIENT IS SET EQUAL TO THE NUMBER
C     OF PASSES COMPLETED AT EXIT FROM LOOP 27. COLUMN 3 OF
C     TABB STORES THE LAYER NUMBER PRIOR TO POINT OF EXIT.
C
      TABB(NSTCDS,1)=CRACK
      IF (K10.EQ.2) TABB(NSTCDS,1) = TABB(NSTCDS,1) /(AOB*2.)
      TABB(NSTCDS,2)=SF
      TABB(NSTCDS,3)=JCNT
      GO TO 780
  770 TABB(NSTCDS,1)=DAA
      IF (K10.EQ.2) TABB(NSTCDS,1) = TABB(NSTCDS,1) /(AOB*2.)
      TABB(NSTCDS,2)=KDX
      TABB(NSTCDS,3)=JDX
  780 CONTINUE
      IF (K10.EQ.2) TWOA(1) =TWOA(1) / (AOB*2.)
      CALL OUTPUT (BLK,JOB)
      IF (K15.EQ.1) CALL PLOTR
      CALL STATUS (IS)
      KHR=IS(8)/360000.
      ISM=IS(8)-(KHR*360000.)
      KMN=ISM/6000.
      SEC=(ISM-(KMN*6000.))/100.
      WRITE (6,980) KHR,KMN,SEC
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790   CONTINUE                                                                TR90616
      GO TO 30                                                                TR90617
      IF ASCENDING ...                                                        TR90618
                                                                              TR90619
                                                                              TR90620
800   FORMAT (1X,F10.7)                                                       TR90621
810   FORMAT (1X,'HUM',25X,'=',F6.4)                                          TR90622
820   FORMAT (1X,20I3)                                                        TR90623
830   FORMAT (1X,'LJOB',24X,'=',I7/' LDECK',23X,'=',I3/' STMAX',23X,'=',TR90624
     1F8.4/' STMIN',23X,'=',F8.4/' DRY',25X,'=',F6.4/' WET',25X,'=',F6.4TR90625
     2/' NRTD',24X,'=',I3/' XCYC',24X,'=',F8.4/' MSETS',23X,'=',I4)     TR90626
840   FORMAT (' RESID1',22X,'=',F6.2/' RESID2',22X,'=',F6.2/' TWOA',24X,TR90627
     1'=',F7.5)                                                         TR90628
850   FORMAT (9I5/18(10F7.3/))                                          TR90629
860   FORMAT (3F10.4)                                                   TR90630
870   FORMAT (' PRESTRESS',19X,'=',F8.3)                                TR90631
880   FORMAT (' DA/DN VS DELTA K DATA IS NOT INCREASING ON CURVE',I4,3X,TR90632
     1'FOR UALUES NO',I4,3X,'AND',I4/' THE NEXT PROBLEM WILL BE ATTEMPTETR90633
     2D')                                                               TR90634
890   FORMAT ('  K11=1 , BUT STMAX = 0   THE NEXT PROBLEM WILL BE ATTEMPTR90635
     1TED')                                                             TR90636
900   FORMAT ('  K8 =1 , BUT DRY = 0   THE NEXT PROBLEM WILL BE ATTEMPTETR90637
     1D')                                                               TR90638
910   FORMAT ('  K10=1 , BUT GMAX = 0   THE NEXT PROBLEM WILL BE ATTEMPTTR90639
     1ED')                                                              TR90640
920   FORMAT ('  KEY6=1 , BUT FIRST BOEING MK VALUE =0   THE NEXT PROBLETR90641
     1M WILL BE ATTEMPTED')                                             TR90642
930   FORMAT (' NRTD=',I3,'ILLEGAL VALUE - THE NEXT PROBLEM WILL BE ATTETR90643
     1MPTED')                                                           TR90644
940   FORMAT (5X,'JP4')                                                 TR90645
950   FORMAT (5X,'DISTILLED WATER')                                     TR90646
960   FORMAT (' IERR=',I4/' THE NEXT PROBLEM WILL BE ATTEMPTED')        TR90647
970   FORMAT (' NPAS',24X,'=',I5/' ILR',25X,'=',I5)                     TR90648
980   FORMAT ('  THE TIME IS NOW',I3,'-',I2,'-',F5.2)                   TR90649
990   FORMAT (1X,'IS(2)=',I4,4X,'IS(3)=',I4)                            TR90650
1000  FORMAT (1X,16A4/)                                                 TR90651
1010  FORMAT (20I2)                                                     TR90652
1020  FORMAT (6F10.5)                                                   TR90653
 1030 FORMAT (3I5,5X, 3F10.0)                                           TR90654
1040  FORMAT (11F5.0,2I5)                                               TR90655
1050  FORMAT (F10.0,6I5,2F10.0,I6)                                      TR90656
1060  FORMAT (5F10.0)                                                   TR90657
1070  FORMAT (5F10.0,I10)                                               TR90658
1080  FORMAT (10I5)                                                     TR90659
1090  FORMAT (10F5.0)                                                   TR90660
1100  FORMAT (I6,I4,5F10.0)                                             TR90661
1110  FORMAT (11F5.3)                                                   TR90662
1120  FORMAT (1X,11F6.3)                                                TR90663
1130  FORMAT (1H ,'A OVER B RATIO',14X,'=',F8.5/1H ,'PHI SQUARED',17X,'=TR90664
     1',F8.5/1H ,'TENSILE YIELD STRENGTH',6X,'=',F8.2,' KSI'/1H ,'STRESSTR90665
     2 INTENSITY FACTOR KC  =',F8.2/1H ,'STRESS INTENSITY FACTOR KIC =',TR90666
     3F8.2/1H ,'DA/DN DELTA K THRESHOLD     =',F8.2/1H ,'DA/DT DELTA K TTR90667
     4HRESHOLD      =',F8.2/1H0,'THE NUMBER OF PASSES TO BE MADE IS',I6/1TR90668
     5H0,'THE TOTAL NUMBER OF LAYERS IS      ',I6)                      TR90669
1140  FORMAT (1H1,15X,'AS READ',29X,'AS REARRANGED'/1H ,'****','********TR90670
     1************************  *******************','*****************TR90671
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```
     2***'/)                                                          TR90672
1150  FORMAT (' COND.   SMEAN    SALT   CYCLES   RATE     SMIN    SMAX   TR90673
     1CYCLES   RATE    DEL S'//)                                       TR90674
1160  FORMAT (' COND.    SMIN    SMAX   CYCLES   RATE     SMIN    SMAX   TR90675
     1CYCLES   RATE    DEL S'//)                                       TR90676
1170  FORMAT (1H ,A4,2F8.2,F9.1,3F8.2,F9.1,2F8.2)                       TR90677
1180  FORMAT (1H1//' PASS NUMBER ',I5)                                 TR90678
1190  FORMAT (1H0,'LAYER    SMIN    SMAX   CYCLES   RATE    DEL K      TR90679
     1 DA/DN(DT)        2AF     RETARD'//)                             TR90680
1200  FORMAT (1H0,'DELTA K IS GREATER THAN 0.9KIC'/1H ,'THE VALUES AT POTR90681
     1INT OF EXIT WERE AS FOLLOWS'/)                                   TR90682
1210  FORMAT (1H0,I5,1X,2F8.2,F9.1,F8.2,F10.3,2X,E14.7,F12.5,F10.6)     TR90683
1220  FORMAT (1H0,'2A IS GREATER THAN THE WIDTH'/1H ,'THE VALUES AT POINTR90684
     1T OF EXIT WERE AS FOLLOWS'/)                                     TR90685
1230  FORMAT (1H ,12X,A4,4X,F8.4)                                      TR90686
1240  FORMAT (1H0,'DELTA K IS GREATER THAN 0.9KC'/1H ,'THE VALUES AT POITR90687
     1NT OF EXIT WERE AS FOLLOWS'/)                                    TR90688
1250  FORMAT (1H1,'THE MULTIPLIER FOR THE NUMBER OF CYCLES IS',F8.3)   TR90689
1260  FORMAT (1H0,'THE FOLLOWING SET OF CONDITION MULTIPLIERS',/1H ,'WILTR90690
     1L BE APPLIED TO THE SPECTRUM'//1H ,8X,'CONDITION',2X,'MULTIPLIER'/TR90691
     2)                                                                TR90692
1270  FORMAT (1H0,'THICKNESS',19X,'=',F8.5,' INCH(S)'/1H ,'WIDTH',23X,'=TR90693
     1 INFINITE'/)                                                     TR90694
1280  FORMAT (1H0,'THICKNESS',19X,'=',F8.5,' INCH(S)'/1H ,'WIDTH',23X,'=TR90695
     1',F8.2,' INCH(S)'/)                                              TR90696
1290  FORMAT (16A4)                                                    TR90697
1300  FORMAT (' KR1 = ',I5,10X,'KR2 = ',I5)                            TR90698
1310  FORMAT (12F5.0)                                                  TR90699
1320  FORMAT (5X,'LAB AIR')                                            TR90700
1330  FORMAT (5X,'HIGH HUMIDITY')                                      TR90701
1340  FORMAT (' THE FOLLOWING ENVIRONMENT(S) USED IN THIS PROBLEM')    TR90702
1350  FORMAT (5X,'DRY AIR')                                            TR90703
1360  FORMAT (5X,'ENVIRONMENTAL DATA AS ENTERED IN PROBLEM INPUT')     TR90704
 1400 FORMAT ( 2I5,10A4, 3I5)                                          TR90705
 1410 FORMAT (  3( E10.3 ,2F5.0) ,   F5.0)                             TR90706
 1420 FORMAT (5X,22HPARIS EQUATION WITH - ,10A4 / 5X,18HDADN = C*DELTAK*TR90707
     1*N                //10X,'C',12X,'N',4X,'DKMAX', 7X,' R')         TR90708
 1430 FORMAT (5X,23HFORMAN EQUATION WITH - ,10A4/ 5X,37HDADN = C*DELTAK*TR90709
     1*N /((1-R)*KC-DELTAK) //10X,'C',12X,'N',4X,'DKMAX', 7X,'KC')     TR90710
 1440 FORMAT (5X,E10.3, 5X, F5.2, 3X, F5.1 , 4X, F7.3 )                TR90711
 1450 FORMAT (1H ,'HOLE DIAMETER' , 15X, '=' , F7.4 )                  TR90712
 1460 FORMAT ( ' CONSTANT FACTOR ON DADN' ,5X, '=' , F7.4)             TR90713
      END                                                              TR90714
```

```
      SUBROUTINE ADPDA(R1,DADN,DELK,NSEG,DACON,DSLOPE,DKMAX,RVAL,IPF,
     1NRC )
      DIMENSION NSEG(3),DACON(3,3),DSLOPE(3,3),DKMAX(3,3),RVAL(3)
      DENOM =1.0
      IF (IPF.EQ.1) DENOM = (1.-R1) *RVAL(1) -DELK
      KURV = 2
      IF (NRC.EQ.3.AND.R1.GT.RVAL(2)) KURV = 3
      IF (IPF.EQ.1.OR.NRC.EQ.1) KURV=1
      KOUNT =0
   10 NLINE = NSEG(KURV)
      DO 20 I=1,NLINE
      IF (DELK.LE.DKMAX(KURV,I)) GO TO 30
   20 CONTINUE
      I=NLINE
   30 DADN=ABS((DACON(KURV,I)* DELK**DSLOPE(KURV,I))/DENOM)
      IF (IPF.EQ.1.OR.NRC.EQ.1) RETURN
      KOUNT = KOUNT + 1
      IF (KOUNT.EQ.1) GO TO 40
      DADN1= DADN
      DADN = EXP (ALOG(DADN1) + (ALOG(DADN2)-ALOG(DADN1))*(R1-RVAL(KURV)
     1)/ (RVAL(KURV+1)- RVAL(KURV)))
      RETURN
   40 KURV = KURV - 1
      DADN2 = DADN
      GO TO 10
      END
```

```
      SUBROUTINE DELTAK                                                 DELT0010
      COMMON SMININ(1000),SMAXIN(1000),CYCIN(1000),COND(1000),INDEX(10),DELT0020
     1SMULT(10),NLARS(10),SMIN(1000),SMAX(1000),CYC(1000),DELS(1000),TWODELT0030
     2A(10),TABA(3000,14),TABB(14,6),MOVER,NCOND,MSETS,XCYC,T,AOB,FYS,KCDELT004
     3,KIC,SF,PHISQ,EXM(14),NTWOA,JCNT,ALFA,C,J,IPASS,CRACK,DELK,SRATIO,DELT0050
     4WIDTH,BOT,ETA,DADN,ICHK,LIO,KEY1,KEY2,KEY3,KEY4,KEY5,KEY6,KEY7,K12DELT0060
      COMMON K13,K17,ISEG(1000),RATEN(1000),AM(11),HUM,K14,K15,IPROB,RR(DELT0070
     11000),K8,K9,K16,DEK(10,20),DEDN(10,20),MD1,MD2,MD3,MD4,MD5,MD6,MD7DELT0080
     2,MD8,MD9,MD(10),IMD,NRTD,DDDA,DUM1,E1,ARY1,DUM3,ARY2,AK1,RY1,RY2,KDELT0090
     3A9,KEY,K10,DRY,WET,JWD,KCC,INDX,ICYC,ITWOA,CYCTD,TIMTD,INX,AREF,GMDELT0100
     4AX,GMIN,PTITLE(3,16),LTITLE(2,16),LJOB,LDECK,IJOB,IDECK,K11,IERR,IDELT0110
     5S(12),STMAX,STMIN,NRD,NSTCDS,XFACT,IQ(1000),NA                    DELT0120
      DIMENSION AN(11)                                                  DELT0130
      DATA AN/1.0,1.0,1.0,1.0,1.004,1.012,1.02,1.027,1.035,1.043,1.5/   DELT0140
      IF (KEY6.EQ.1) GO TO 20                                           DELT0150
      DO 10 II=1,11                                                     DELT0160
      AM(II)=AN(II)                                                     DELT0170
10    CONTINUE                                                          DELT0180
      IF (KEY6.EQ.2) KEY6=1                                             DELT0190
20    CONTINUE                                                          DELT0200
C                                                                       DELT0210
C     THIS SUBROUTINE CALCULATES DELTA K FOR EITHER A PART-             DELT0220
C     THRU CRACK OR A THRU CRACK FROM THE MAXIMUM AND MINIMUM           DELT0230
C     STRESSES FOR A GIVEN LAYER. A CORRECTION FACTOR , M (EM),         DELT0240
C     WHICH IS A FUNCTION OF THE APPLIED STRESS, IS USED TO             DELT0250
C     ADJUST K AS THE CRACK APPROACHES THE OPPOSITE SIDE OF             DELT0260
      THE PLATE.                                                        DELT0270
                                                                        DELT0280
      FOR A THRU CRACK, BOT IS GREATER THAN OR EQUAL TO 1.              DELT0290
                                                                        DELT0300
      IF (BOT.GE.1.) GO TO 100                                          DELT0310
      PICB=1.21*3.1416*CRACK/(2.0*AOB)                                  DELT0320
C                                                                       DELT0330
C     SUBROUTINE AFIT DEFINES THE EM VS. BOT CURVES FOR VALUES          DELT0340
C     OF SRATIO. TANBOT IS FOUND IN AFIT AS ARE Y2 AND SLOPE.           DELT0350
C                                                                       DELT0360
      SRATIO=SMAX(J)/FYS                                                DELT0370
      IF (KEY6.NE.0) GO TO 40                                           DELT0380
      IF (BOT.LT.0.61) GO TO 30                                         DELT0390
      CALL AFIT (AOB,PHISQ,SLOPE,SRATIO,TANBOT)                         DELT0400
      IF (BOT.LT.TANBOT) GO TO 30                                       DELT0410
      IF (BOT.GE.TANBOT) EM=Y2+SLOPE*(BOT-1.0)                          DELT0420
      GO TO 70                                                          DELT0430
30    EM=SQRT(C*TAN(ALFA*BOT)/(ALFA*BOT))                               DELT0440
      GO TO 70                                                          DELT0450
40    AGH=0.0                                                           DELT0460
      DO 50 IK=2,11                                                     DELT0470
      AGH=AGH+0.1                                                       DELT0480
      IF (BOT.LE.AGH) GO TO 60                                          DELT0490
50    CONTINUE                                                          DELT0500
      IK=11                                                             DELT0501
60    IK1=IK-1                                                          DELT0510
      EM=AM(IK)+(BOT-AGH)*10.0*(AM(IK)-AM(IK1))                         DELT0520
70    AKMAX=SQRT((PICB*SMAX(J)**2)/(PHISQ-0.212*SRATIO**2))*EM          DELT0530
      SRATIO=SMIN(J)/FYS                                                DELT0540
      IF (KEY6.NE.0) GO TO 90                                           DELT0550
```

```
      IF (BOT.LT.0.61) GO TO 80
      CALL AFIT (AOB,PHISQ,SLOPE,SRATIO,TANBOT)
      IF (BOT.LT.TANBOT) GO TO 80
      IF (BOT.GE.TANBOT) EM=Y2+SLOPE*(BOT-1.0)
      GO TO 90
80    EM=SQRT(C*TAN(ALFA*BOT)/(ALFA*BOT))
90    AKMIN=SQRT((PICB*SMIN(J)**2)/(PHISQ-0.212*SRATIO**2))*EM
      GO TO 120
C
C     TEST FOR INFINITE WIDTH PLATE....
C
100   IF (KEY1.EQ.0) GO TO 110
C
      AKMAX=SQRT((3.1416*CRACK*SMAX(J)**2)/(2.0-(SMAX(J)/FYS)**2))
      AKMIN=SQRT((3.1416*CRACK*SMIN(J)**2)/(2.0-(SMIN(J)/FYS)**2))
      GO TO 120
110   CW=CRACK/WIDTH
      Y=1.0+0.1565*CW-0.2881*CW**2+1.5254*CW**3
      AKMAX=SQRT((3.1416*CRACK*SMAX(J)**2)/(2.0-(SMAX(J)/FYS)**2))*Y
      AKMIN=SQRT((3.1416*CRACK*SMIN(J)**2)/(2.0-(SMIN(J)/FYS)**2))*Y
C
120   DELK=ABS(AKMAX-AKMIN)
      AK1=AKMAX
      IF (AKMAX.LT.AKMIN) AK1=AKMIN
C
      RETURN
C
      END
```

```
      SUBROUTINE SEQENC
      COMMON SMININ(1000),SMAXIN(1000),CYCIN(1000),COND(1000),INDEX(10),
     1SMULT(10),NLARS(10),SMIN(1000),SMAX(1000),CYC(1000),DELS(1000),TWO
     2A(10),TABA(3000,14),TABB(14,6),MOVER,NCOND,MSETS,XCYC,T,AOB,FYS,KC
     3,KIC,SF,PHISQ,EXM(14),NTWOA,JCNT,ALFA,C,J,IPASS,CRACK,DELK,SRATIO,
     4WIDTH,BOT,ETA,DADN,ICHK,LIO,KEY1,KEY2,KEY3,KEY4,KEY5,KEY6,KEY7,K12
      COMMON K13,K17,ISEG(1000),RATEN(1000),AM(11),HUM,K14,K15,IPROB,RR(
     11000),K8,K9,K16,DEK(10,20),DEDN(10,20),MD1,MD2,MD3,MD4,MD5,MD6,MD7
     2,MD8,MD9,MD(10),IMD,NRTD,DDDA,DUM1,E1,ARY1,DUM3,ARY2,AK1,RY1,RY2,K
     3A9,KEY,K10,DRY,WET,JWD,KCC,INDX,ICYC,ITWOA,CYCTD,TIMTD,INX,AREF,GM
     4AX,GMIN,PTITLE(3,16),LTITLE(2,16),LJOB,LDECK,IJOB,IDECK,K11,IERR,I
     5S(12),STMAX,STMIN,NRD,NSTCDS,XFACT,IQ(1000),NA
C
C     THIS SUBROUTINE SEQUENCES THE ARRAYS SMIN, SMAX, CYC,
C     AND DELS IN ASCENDING ORDER (KEY4=1) OF DELTA STRESS
C     (STORED IN ARRAY DELS) OR IN DESCENDING ORDER (KEY4=2).
C
      JCNTM1=JCNT-1
      DO 40 IT=1,JCNTM1
      B=DELS(IT)
      BA=SMIN(IT)
      BB=SMAX(IT)
      BC=CYC(IT)
      BE=RATEN(IT)
      IZ=JCNT-IT
      BQ=IQ(IT)
      BR=RR(IT)
      DO 30 JJ=1,IZ

      TEST FOR SEQUENCING ORDER ....

      IF (KEY4.EQ.2) GO TO 10
C
C
      IF (B-DELS(IT+JJ)) 30,30,20
C
C     IF DESCENDING ...
10    IF (B-DELS(IT+JJ)) 20,30,30
C
20    DB=DELS(IT+JJ)
      DBA=SMIN(IT+JJ)
      DBB=SMAX(IT+JJ)
      DBC=CYC(IT+JJ)
      DBE=RATEN(IT+JJ)
      DBQ=IQ(IT+JJ)
      DBR=RR(IT+JJ)
      DELS(IT+JJ)=B
      SMIN(IT+JJ)=BA
      SMAX(IT+JJ)=BB
      CYC(IT+JJ)=BC
      RATEN(IT+JJ)=BE
      IQ(IT+JJ)=BQ
      RR(IT+JJ)=BR
      B=DB
      BA=DBA
      BB=DBB
```

```
      BC=DBC                                                            SENC0570
      BE=DBE                                                            SENC0580
      BQ=DBQ                                                            SENC0590
      BR=DBR                                                            SENC0600
   30 CONTINUE                                                          SENC0610
      DELS(IT)=B                                                        SENC0620
      SMIN(IT)=BA                                                       SENC0630
      SMAX(IT)=BB                                                       SENC0640
      CYC(IT)=BC                                                        SENC0650
      RATEN(IT)=BE                                                      SENC0660
      IQ(IT)=BQ                                                         SENC0670
      RR(IT)=BR                                                         SENC0680
   40 CONTINUE                                                          SENC0690
      RETURN                                                            SENC0700
      END                                                               SENC0710
```

```
      SUBROUTINE COMP1 (DADN,KEY7,R1,RATE,DELK)                         COM00010
      DIMENSION AJ(9,3), DJ(9,3), AH(9,5), DH(9,5), ND(9)               COM00020
      DATA AJ,DJ,AH,DH,ND/0.43,0.365,0.365,0.46,0.38,0.38,0.49,0.4,0.4,3COM00030
     19.,28.5,28.5,17.,12.5,12.5,6.2,4.4,4.4,9*100.0,9*7.0,39.7,37.5,37.COM00040
     25,28.0,26.5,26.5,18.5,17.5,17.5,3*47.0,3*37.0,3*30.0,1.57,0.98,1.0COM00050
     35,1.57,1.11,1.45,1.57,2.07,1.48,65.1,13.1,6.5,65.1,16.0,7.73,32.9,COM00060
     49.38,8.74,100.3,27.1,13.6,74.2,25.1,15.4,195.3,11.8,268.4,243.9,19COM00070
     52.8,21.7,210.8,100.1,17.2,0.0,254.1,0.0,0.0,0.0,205.1,0.0,0.0,198.COM00080
     62,3*0.0,9*7.0,26.1,20.02,17.47,26.1,19.8,16.01,20.5,16.95,20.5,37.COM00090
     71,37.5,30.13,29.0,29.0,27.43,25.5,20.5,31.0,41.0,47.5,37.5,32.8,34COM00100
     8.0,29.0,0.0,30.0,0.0,0.0,0.0,49.0,0.0,0.0,39.00,3*0.0,4,4,5,4,4,5,COM00110
     93,4,3/                                                            COM00120
      IMD=7                                                             COM00130
      IF (R1.LT.0.2) IMD=1                                              COM00140
      IF (R1.LT.0.4.AND.R1.GE.0.2) IMD=4                                COM00150
      IF (RATE.GT.59.9) IMD=IMD+1                                       COM00160
      IF (RATE.GT.179.9) IMD=IMD+1                                      COM00170
      IF (KEY7.LE.1) GO TO 30                                           COM00180
      KK=ND(IMD)                                                        COM00190
      DO 10 IZ=2,KK                                                     COM00200
      IF (DH(IMD,IZ).GE.DELK) GO TO 20                                  COM00210
 10   CONTINUE                                                          COM00220
      IZ = KK                                                           COM00221
 20   IY=IZ-1                                                           COM00230
      DK1=ALOG(DH(IMD,IY))                                              COM00240
      DK2=ALOG(DH(IMD,IZ))                                              COM00250
      DA1=ALOG(AH(IMD,IY))                                              COM00260
      DA2=ALOG(AH(IMD,IZ))                                              COM00270
      GO TO 60                                                          COM00280
 30   DO 40 IZ=2,3                                                      COM00290
      IF (DJ(IMD,IZ).GE.DELK) GO TO 50                                  COM00300
 40   CONTINUE                                                          COM00310
      IZ=3                                                              COM00311
 50   IY=IZ-1                                                           COM00320
      DK1=ALOG(DJ(IMD,IY))                                              COM00330
      DK2=ALOG(DJ(IMD,IZ))                                              COM00340
      DA1=ALOG(AJ(IMD,IY))                                              COM00350
      DA2=ALOG(AJ(IMD,IZ))                                              COM00360
 60   D=ALOG(DELK)                                                      COM00370
      DADN=0.000001*EXP(((D-DK1)*(DA2-DA1)/(DK2-DK1))+DA1)              COM00380
      RETURN                                                            COM00390
      END                                                               COM00400
```

```
      SUBROUTINE WRITIN (CCYC,JX,L2)
      COMMON SMININ(1000),SMAXIN(1000),CYCIN(1000),COND(1000),INDEX(10),
     1SMULT(10),NLARS(10),SMIN(1000),SMAX(1000),CYC(1000),DELS(1000),TWO
     2A(10),TABA(3000,14),TABB(14,6),MOVER,NCOND,MSETS,XCYC,T,AOB,FYS,KC
     3,KIC,SF,PHISQ,EXM(14),NTWOA,JCNT,ALFA,C,J,IPASS,CRACK,DELK,SRATIO,
     4WIDTH,BOT,ETA,DADN,ICHK,LIO,KEY1,KEY2,KEY3,KEY4,KEY5,KEY6,KEY7,K12
      COMMON K13,K17,ISEG(1000),RATEN(1000),AM(11),HUM,K14,K15,IPROB,RR(
     11000),K8,K9,K16,DEK(10,20),DEDN(10,20),MD1,MD2,MD3,MD4,MD5,MD6,MD7
     2,MD8,MD9,MD(10),IMD,NRTD,DDDA,DUM1,E1,ARY1,DUM3,ARY2,AK1,RY1,RY2,K
     3A9,KEY,K10,DRY,WET,JWD,KCC,INDX,ICYC,ITWOA,CYCTD,TIMTD,INX,AREF,GM
     4AX,GMIN,PTITLE(3,16),LTITLE(2,16),LJOB,LDECK,IJOB,IDECK,K11,IERR,I
     5S(12),STMAX,STMIN,NRD,NSTCDS,XFACT,IQ(1000),NA
      JX=JX+1
      IF (JX.LE.(22+24*INX)) GO TO 10
      WRITE (6,30)
      INX=INX+1
10    IF (L2.EQ.1) WRITE (6,20) J,SMIN(J),SMAX(J),CCYC,RATEN(J),DELK
      IF (L2.EQ.2) WRITE (6,20) J,SMIN(J),SMAX(J),CCYC,RATEN(J),DELK,DAD
     1N,CRACK,DUM1
      IF (L2.EQ.3) WRITE (6,20) J,SMIN(J),SMAX(J),CCYC,RATEN(J)
      RETURN
C
C
20    FORMAT (1H0,I5,1X,2F8.2,F9.1,F8.2,F10.3,2X,E14.7,F12.5,F10.6)
30    FORMAT (1H1,'LAYER    SMIN     SMAX     CYCLES     RATE       DEL K
     1 DA/DN(DT)          2AF        RETARD'//)
      END
```

```
      SUBROUTINE AFIT (AOB,PHISQ,SLOPE,SRATIO,TANBOT)
C     THIS SUBROUTINE CALCULATES THE SLOPE OF THE MK VS BOT LINE FOR
C     BOT GREATER THAN 0.61
      SQ=SRATIO**2
      Y2=SQRT(1.65*AOB*(PHISQ-0.212*SQ)/(2.0-SQ))
      IF (SRATIO.LE.0.5) GO TO 10
      X1=0.65
      Y1=1.1493
      GO TO 20
10    X1=0.61
      Y1=1.1078
20    CONTINUE
      SLOPE=(Y2-Y1)/(1.0-X1)
      TANBOT=X1
      RETURN
      END
```

```
      SUBROUTINE CN (RATE,KA9,R1,KEY7,DADN,DELK)
C     THIS SUBROUTINE CHOOSES THE APPROPRIATE SEE AND ETA VALUES
      DATA AT1,C1,C2,C3,C4,C5,C6,C7,C8,C9,C10/2.6,0.0016,0.0022,0.0025,0
     1.0030,0.0031,0.0034,0.0036,0.0025,0.0027,0.0029/
      IF (KA9.EQ.1) GO TO 30
      IF (KEY7.EQ.0.OR.KEY7.EQ.2) GO TO 40
      GO TO 50
   10 SEE1=C1
      GO TO 110
   20 SEE1=C2
      GO TO 110
   30 IF (R1.LT.0.2) GO TO 10
      IF (R1.LT.0.4) GO TO 20
      SEE1=C3
      GO TO 110
   40 SEE1=C4
      GO TO 110
   50 IF (RATE.GT.7.0) GO TO 80
      IF (R1.LT.0.2) GO TO 70
      IF (R1.LT.0.4) GO TO 60
      SEE1=C7
      GO TO 110
   60 SEE1=C6
      GO TO 110
   70 SEE1=C5
      GO TO 110
   80 IF (R1.LT.0.2) GO TO 100
      IF (R1.LT.0.4) GO TO 90
      SEE1=C10
      GO TO 110
   90 SEE1=C9
      GO TO 110
  100 SEE1=C8
  110 ETA1=AT1
      DADN=0.000001*SEE1*DELK**ETA1
      RETURN
      END
```

```
      SUBROUTINE COMPKL (DADN,R1,RATE,DELK,DEK,DEDN,MD)                 COMK0010
      DIMENSION DEK(10,20), DEDN(10,20), MD(10)                         COMK0020
C     THIS SUBROUTINE DEFINES A CRACK GROWTH RATE (DA/DN) FOR VARIOUS   COMK0030
C     R VALUES AND A GIVEN VALUE OF DELTA K. IT THEN CALCULATES A NEW   COMK0040
C     BOT AND CRACK LENGTH.                                             COMK0050
      IMD=7                                                             COMK0060
      IF (R1.LT.0.2) IMD=1                                              COMK0070
      IF (R1.LT.0.4.AND.R1.GE.0.2) IMD=4                                COMK0080
      IF (RATE.GT.59.9) IMD=IMD+1                                       COMK0090
      IF (RATE.GT.179.9) IMD=IMD+1                                      COMK0100
      KK=MD(IMD)                                                        COMK0110
      DO 10 IZ=2,KK                                                     COMK0120
      IF (DEK(IMD,IZ).GE.DELK) GO TO 20                                 COMK0130
10    CONTINUE                                                          COMK0140
      IZ=KK                                                             COMK0141
20    IY=IZ-1                                                           COMK0150
      DK1=ALOG(DEK(IMD,IY))                                             COMK0160
      DK2=ALOG(DEK(IMD,IZ))                                             COMK0170
      DA1=ALOG(DEDN(IMD,IY))                                            COMK0180
      DA2=ALOG(DEDN(IMD,IZ))                                            COMK0190
      D=ALOG(DELK)                                                      COMK0200
      DADN=0.000001*EXP(((D-DK1)*(DA2-DA1)/(DK2-DK1))+DA1)              COMK0210
      RETURN                                                            COMK0220
      END                                                               COMK0230
```

```
      SUBROUTINE OUTPUT (BLK,JOB)
      COMMON SMININ(1000),SMAXIN(1000),CYCIN(1000),COND(1000),INDEX(10),
     1SMULT(10),NLARS(10),SMIN(1000),SMAX(1000),CYC(1000),DELS(1000),TWO
     2A(10),TABA(3000,14),TABB(14,6),MOVER,NCOND,MSETS,XCYC,T,AOB,FYS,KC
     3,KIC,SF,PHISQ,EXM(14),NTWOA,JCNT,ALFA,C,J,IPASS,CRACK,DELK,SRATIO,
     4WIDTH,BOT,ETA,DADN,ICHK,LIO,KEY1,KEY2,KEY3,KEY4,KEY5,KEY6,KEY7,K12
      COMMON K13,K17,ISEG(1000),RATEN(1000),AM(11),HUM,K14,K15,IPROB,RR(
     11000),K8,K9,K16,DEK(10,20),DEDN(10,20),MD1,MD2,MD3,MD4,MD5,MD6,MD7
     2,MD8,MD9,MD(10),IMD,NRTD,DDDA,DUM1,E1,ARY1,DUM3,ARY2,AK1,RY1,RY2,K
     3A9,KEY,K10,DRY,WET,JWD,KCC,INDX,ICYC,ITWOA,CYCTD,TIMTD,INX,AREF,GM
     4AX,GMIN,PTITLE(3,16),LTITLE(2,16),LJOB,LDECK,IJOB,IDECK,K11,IERR,I
     5S(12),STMAX,STMIN,NRD,NSTCDS,XFACT,IQ(1000),NA
C
C     THIS SUBROUTINE PRINTS THE SUMMARY TABLES TABA AND TABB.
C
      INTEGER SF
      IP=0
C
C     THE HEADING FOR THE FIRST TABLE AND THE INITIAL CRACK
C     LENGTHS ARE NOW PRINTED.
C
      IF (MSETS.GT.7) IP=1
C
      IF (NRTD.EQ.0.OR.NRTD.EQ.2) WRITE (6,300)
      IF (NRTD.EQ.1) WRITE (6,310)
      IF (MSETS.GT.7) WRITE (6,330) (EXM(MQ),MQ=1,7)
      IF (MSETS.LE.7) WRITE (6,330) (EXM(MO),MO=1,MSETS)
      IF (IP.GT.0) GO TO 10
      WRITE (6,340) (TWOA(1),II=1,MSETS)
      GO TO 20
10    WRITE (6,340) (TWOA(1),II=1,7)
20    CONTINUE
      NCT=0
C
C     LOOP 33 ESSENTIALLY PRINTS OUT THE FIRST TABLE.
C
      DO 90 MN=1,SF
      IF (IP.GT.0) GO TO 50
C
C     LOOP 39 ESTABLISHES THE PRINT INDEX JJA. IT ALSO TESTS
C     TABA FOR ZEROS AS A PRINTING STOP.
C
      DO 30 NN=1,MSETS
      IF (TABA(MN,NN).NE.0.0) GO TO 30
      IF (NN.EQ.1) GO TO 100
      JJA=NN-1
      GO TO 40
30    CONTINUE
      JJA=MSETS
40    WRITE (6,350) MN,(TABA(MN,NJ),NJ=1,JJA)
      GO TO 80

      LOOP 41 SERVES THE SAME PURPOSE AS LOOP 39 BUT IS USED
      WHEN THERE ARE MORE THAN 7 INITIAL CRACK LENGTHS

50    DO 60 NN=1,7
```

```
      IF (TABA(MN,NN).NE.0.0) GO TO 60
      IF (NN.EQ.1) GO TO 100
      JJA=NN-1
      GO TO 70
60    CONTINUE
      JJA=7
70    WRITE (6,350) MN,(TABA(MN,NJ),NJ=1,JJA)
80    IF (MN.LE.(45+47*NCT)) GO TO 90
      WRITE (6,320)
      IF (MSETS.GT.7) WRITE (6,330) (EXM(MQ),MQ=1,7)
      IF (MSETS.LE.7) WRITE (6,330) (EXM(MQ),MQ=1,MSETS)
      NCT=NCT+1
90    CONTINUE
C
C     IF THERE ARE MORE THAN 7 INITIAL CRACK LENGTHS THE FIRST
C     TABLE IS NOW COMPLETED.
C
100   IF (IP) 150,150,110
110   WRITE (6,360)
      WRITE (6,330) (EXM(MQ),MQ=8,MSETS)
      WRITE (6,340) (TWOA(1),II=8,MSETS)
      NCT=0
C
C     LOOP 35 PRINTS OUT REST OF FIRST TABLE.
C     LOOP 43 ESTABLISHES THE PRINT INDEX JJA.
C
      DO 140 MN=1,SF
      DO 120 NN=8,MSETS
      IF (TABA(MN,NN).NE.0.0) GO TO 120
      IF (NN.EQ.8) GO TO 150
      JJA=NN-1
      GO TO 130
120   CONTINUE
      JJA=MSETS
130   WRITE (6,350) MN,(TABA(MN,NJ),NJ=8,JJA)
      IF (MN.LE.(45+47*NCT)) GO TO 140
      WRITE (6,360)
      WRITE (6,330) (EXM(MQ),MQ=8,MSETS)
      NCT=NCT+1
140   CONTINUE
150   CONTINUE
      WRITE (6,370)
C
C     LOOP 36 PRINTS THE TEST CONDITION IDENTIFICATIONS AND
C     THEIR MULTIPLIERS.
C
      JKLA=1
      DO 160 JKL=1,NCOND
      WRITE (6,380) COND(JKLA),SMULT(JKL)
      JKLA=1+INDEX(JKL)
160   CONTINUE
      WRITE (6,390) SF
      WRITE (6,400)
C
C     LOOP 37 PRINTS THE INITIAL AND FINAL CRACK LENGTHS AND
C     THE PASS AND LAYER NUMBERS ASSOCIATED WITH THE FINAL
```

```
C      CRACK LENGTH. A STATEMENT IS ALSO PRINTED EXPLAINING
C      ANY ABNORMAL EXIT ASSOCIATED WITH THE FINAL CRACK LENGTH.

       DO 240 KJ=1,MSETS

       SINCE INDICES WILL BE ESTABLISHED FROM COLUMNS 2 AND 3
C      OF TABB, PROPER ROUND OFF OF THOSE QUANTITIES MUST BE
C      MADE IN CONVERTING THEM TO INTEGER VARIABLES.
C
       KXD=TABB(KJ,3)+0.1
       JXD=TABB(KJ,2)+0.1
       CRACK=TABB(KJ,1)
       BT=CRACK/(2.0*AOB*T)
       IF (KEY1.EQ.1) GO TO 170
       IF (CRACK.LT.WIDTH) GO TO 170
       WRITE (6,410) TWOA(1),TABB(KJ,1),JXD,KXD
       GO TO 240
170    IF (BT.LT.1.0) GO TO 200
       IF (KXD.EQ.0) GO TO 180
       IF (KXD.EQ.JCNT.AND.JXD.EQ.SF) GO TO 230
       JXA=TABB(KJ,5)+0.1
       KXA=TABB(KJ,6)+0.1
       WRITE (6,420) TWOA(1),TABB(KJ,4),JXA,KXA
       WRITE (6,430) TABB(KJ,1),JXD,KXD
       GO TO 240
180    IF (JXD.EQ.1) GO TO 190
       JXD=JXD-1
       KXD=JCNT
       JXA=TABB(KJ,5)+0.1
       KXA=TABB(KJ,6)+0.1
       WRITE (6,420) TWOA(1),TABB(KJ,4),JXA,KXA
       WRITE (6,430) TABB(KJ,1),JXD,KXD
       GO TO 240
190    WRITE (6,440) TWOA(1),TWOA(1)
       GO TO 240
200    IF (KXD.EQ.0) GO TO 210
       IF (KXD.EQ.JCNT.AND.JXD.EQ.SF) GO TO 230
       WRITE (6,450) TWOA(1),TABB(KJ,1),JXD,KXD
       GO TO 240
210    IF (JXD.EQ.1) GO TO 220
       JXD=JXD-1
       KXD=JCNT
       WRITE (6,450) TWOA(1),TABB(KJ,1),JXD,KXD
       GO TO 240
220    WRITE (6,460) TWOA(1),TWOA(1)
       GO TO 240
230    WRITE (6,470) TWOA(1),TABB(KJ,1),JXD,KXD
240    CONTINUE
       IF (LIO.LT.10) GO TO 290
       ICNT=0
       DO 280 JJ=1,MSETS
       ICNT=ICNT+1
       IF (ICNT.GT.1) LIO=LIO+20
       ISF1=(TABB(JJ,2)-1)/3
       ITB=TABB(JJ,2)+0.1
       WRITE (7,480) ITB,JOB,LIO
```

```
      X11=0.0                                                           OTPT1700
      X21= 200.0* BLK                                                   OTPT171
      X31= 400.0* BLK                                                   OTPT172
      ISEQ1=IPROB                                                       OTPT1730
      WRITE (7,490) X11,TWOA(1)     ,X21,TABA(1,JJ)  ,X31,TABA(2,JJ) ,  OTPT1740
     1JOB,LIO,ISEQ1                                                     OTPT1741
      DO 270 IJ1=1,ISF1                                                 OTPT1750
      IX1=IJ1*3                                                         OTPT1760
      IX2=IX1+1                                                         OTPT1770
      MN=IX1+2                                                          OTPT1780
      ISEQ1=ISEQ1+1                                                     OTPT1790
      X11= IX1 * 200. * BLK                                             OTPT180
      X21= IX2 * 200. * BLK                                             OTPT181
      X31= MN  * 200. * BLK                                             OTPT182
      IF (ISEQ1.LT.10) GO TO 260                                        OTPT1830
      IF (ISEQ1.GE.100) GO TO 250                                       OTPT1840
      WRITE (7,490) X11,TABA(IX1,JJ),X21,TABA(IX2,JJ),X31,TABA(MN,JJ),  OTPT1850
     1JOB,LIO,ISEQ1                                                     OTPT1860
      GO TO 270                                                         OTPT1870
  250 WRITE (7,500) X11,TABA(IX1,JJ),X21,TABA(IX2,JJ),X31,TABA(MN,JJ),  OTPT1880
     1JOB,LIO,ISEQ1                                                     OTPT1890
      GO TO 270                                                         OTPT1900
  260 WRITE (7,510) X11,TABA(IX1,JJ),X21,TABA(IX2,JJ),X31,TABA(MN,JJ),  OTPT191
     1JOB,LIO,ISEQ1                                                     OTPT1920
  270 CONTINUE                                                          OTPT1930
  280 CONTINUE                                                          OTPT1940
  290 CONTINUE                                                          OTPT1950
      RETURN                                                            OTPT1960
                                                                        OTPT1970
                                                                        OTPT1980
  300 FORMAT (1H1,31X,'CRACK LENGTH   -   RETARDED')                    OTPT1990
  310 FORMAT (1H1,28X,'CRACK LENGTH   -   NO RETARDATION')              OTPT2000
  320 FORMAT (1H1,37X,'CRACK LENGTH')                                   OTPT2010
  330 FORMAT (1H ,' PASS    **********************************','*******OTPT2020
     1****************************'/3X,'M =',7(5X,F5.2))                OTPT2030
  340 FORMAT (1H ,'INITIAL ',6(F9.5,1X),F9.5)                           OTPT2040
  350 FORMAT (1H ,1X,I4,3X, 6(F9.5,1X), F9.5)                           TD9T205
  360 FORMAT (1H1,17X,'CRACK LENGTH')                                   OTPT2060
  370 FORMAT (1H1,'IN SUMMARY,USING THE FOLLOWING SET OF',' CONDITION MUOTPT2070
     1LTIPLIERS,'//1H ,8X,'CONDITION',2X,'MULTIPLIER'/)                 OTPT2080
  380 FORMAT (1H ,12X,A4,4X,F8.4)                                       OTPT2090
  390 FORMAT (1H0,'AND A NUMBER OF LAYERS EQUAL TO',I5)                 OTPT2100
  400 FORMAT (1H0,'THE APPLIED SPECTRUM PRODUCED THE FOLLOWING ','SET OFOTPT2110
     1 CRACK LENGTHS'//1H0,2X,'INITIAL',5X,'FINAL',4X,'PASS',2X,'LAYER',OTPT2120
     24X,'NORMAL EXIT INTERRUPTED BECAUSE',' ON THE'/1H ,38X,'APPLICATIOOTPT2130
     3N OF THE NEXT LAYER ....'/)                                       OTPT2140
  410 FORMAT (1H ,2F10.6,I6,I7,5X,'2A EXCEEDED WIDTH')                  OTPT2150
  420 FORMAT (1H ,2F10.6,I6,I7,5X,'B/T EXCEEDED 1.0')                   OTPT2160
  430 FORMAT (1H ,10X,F10.6,I6,I7,5X,'0.9KC HAS BEEN EXCEEDED')         OTPT2170
  440 FORMAT (1H ,2F10.6,18X,'0.9KC WAS EXCEEDED ON FIRST',' LAYER'/1H ,OTPT2180
     138X,'OF FIRST PASS')                                              OTPT2190
  450 FORMAT (1H ,2F10.6,I6,I7,5X,'0.9KIC HAS BEEN EXCEEDED')           OTPT2200
  460 FORMAT (1H ,2F10.6,18X,'0.9KIC WAS EXCEEDED ON FIRST',' LAYER'/1H OTPT2210
     1,38X,'OF FIRST PASS')                                             OTPT2220
  470 FORMAT (1H ,2F10.6,I6,I7)                                         OTPT2230
  480 FORMAT (5X,I5,56X,I6,'P',I2, 4H0001)                              OTPT224
```

```
490   FORMAT (3(F10.2,F10.7),6X,I6,'P',I2,2H00,I2)                       OTPT2250
500   FORMAT (3(F10.2,F10.7),6X,I6,'P',I2,'0', I3)                       OTPT2260
510   FORMAT (3(F10.2,F10.7),6X,I6,'P',I2,3H000,I1)                      OTPT2270
      END                                                                OTPT2280
```

```
      SUBRCUTINE RDELK (D,FMAX)                                         RDEL001
      COMMON SMININ(1000),SMAXIN(1000),CYCIN(1000),COND(1000),INDEX(10),RDEL002
     1SMULT(10),NLARS(10),SMIN(1000),SMAX(1000),CYC(1000),DELS(1000),TWORDEL003
     2A(10),TABA(3000,14),TABB(14,6),MOVER,NCOND,MSETS,XCYC,T,AOB,FYS,KCRDEL004
     3,KIC,SF,PHISQ,EXM(14),NTWOA,JCNT,ALFA,C,J,IPASS,CRACK,DELK,SRATIO,RDEL005
     4WIDTH,BOT,ETA,DADN,ICHK,LIO,KEY1,KEY2,KEY3,KEY4,KEY5,KEY6,KEY7,K12RDEL006
      COMMON K13,K17,ISEG(1000),RATEN(1000),AM(11),HUM,K14,K15,IPROB,RR(RDEL007
     11000),K8,K9,K16,DEK(10,20),DEDN(10,20),MD1,MD2,MD3,MD4,MD5,MD6,MD7RDEL008
     2,MD8,MD9,MD(10),IMD,NRTD,DDDA,DUM1,E1,ARY1,DUM3,ARY2,AK1,RY1,RY2,KRDEL009
     3A9,KEY,K10,DRY,WET,JWD,KCC,INDX,ICYC,ITWOA,CYCTD,TIMTD,INX,AREF,GMRDEL010
     4AX,GMIN,PTITLE(3,16),LTITLE(2,16),LJOB,LDECK,IJOB,IDECK,K11,IERR,IRDEL011
     5S(12),STMAX,STMIN,NRD,NSTCDS,XFACT,IQ(1000),NA                    RDEL012
      DIMENSION COR(15), FCOR(15)                                       RDEL013
      DATA COR,FCOR /0.001,0.1, 0.2,0.3,0.4,0.5,0.6,0.8,1.0,1.5,2.0,3.0,RDEL014
     15.0,10.0,100.0, 3.39, 2.73, 2.3,2.04,1.86,1.73,1.64,1.47,1.37,1.18RDEL015
     2,1.06,0.94, 0.81,0.75, 0.707 /                                    RDEL016
      CR = CRACK/(AOB * D)                                              RDEL017
      DO 20 L2=2,15                                                     RDEL018
      IF (CR.LE.COR(L2)) GO TO 30                                       RDEL019
   20 CONTINUE                                                          RDEL020
      L2=15                                                             RDEL021
   30 L1=L2-1                                                           RDEL022
      AC= ALOG(CR)                                                      RDEL023
      AC2=ALOG(COR(L2))                                                 RDEL024
      AC1=ALOG(COR(L1))                                                 RDEL025
      FCR = FCOR(L1) +((FCOR(L2)-FCOR(L1)) *(AC-AC1)/ (AC2-AC1))        RDEL026
      IF (FCR.GT.FMAX) FCR=FMAX                                         RDEL0261
      AKMAX = SMAX(J) * FCR * SQRT (3.1416 * CRACK /(2.0 * AOB))        RDEL027
      AKMIN = SMIN(J) * FCR * SQRT (3.1416 * CRACK /(2.0 * AOB))        RDEL028
      DELK = ABS ( AKMAX- AKMIN)                                        RDEL029
      AK1=AKMAX                                                         RDEL030
      IF (AKMAX.LT.AKMIN) AK1=AKMIN                                     RDEL031
C                                                                       RDEL032
      RETURN                                                            RDEL033
C                                                                       RDEL034
      END                                                               RDEL035
```

```
      SUBROUTINE RPLAST (DUM3,DDDA,ARY1,ARY2,AK1,E1,RY1,RY2,DUM1)
      DOUBLE PRECISION DRY1,DDA,DDUM3,DK,DARY1,DARY2,DRY2,DE1,DDUM1,BARY
C     OF PLATIC FRONT ASSOCIATED WITH THE LOAD BEING CALCULATED TO THE
C     LONGEST PLASTIC FRONT LEFT BY A PRECEEDING LOAD
      IF (ARY2.LT.0.0001) DARY2=0.0
      DE1=E1
      DK=AK1
      DDA=DDDA
      DDUM3=DUM3
      IF (ARY2.LT.0.0001) GO TO 10
C
      BARY=DDA+DRY1
      IF (BARY.GT.DARY2) DARY2=BARY
10    CONTINUE
      DRY1=DDUM3*DK*DK
      DARY1=DDA+DRY1
      IF (DARY1.GT.DARY2) DARY2=DARY1
      DRY2=DARY2-DDA
      IF (DRY2.NE.0.) DDUM1=(DRY1/DRY2)**DE1
      DUM1=DDUM1
      RY1=DRY1
      RY2=DRY2
      ARY1=DARY1
      ARY2=DARY2
      RETURN
      END
```

```
      SUBROUTINE CRKGRO (DCRACK,CRACK,DADN,DUM1,AOB,RCY,KNT,KNT1)
      DOUBLE PRECISION XCR,XDCR,XDN,XDUM,XAOB,XRCY,XCR1
C     THIS SUBROUTINE CALCULATES THE INCREMENTAL CRACK GROWTH AND
C     THE NEW CRACK LENGTH FOR THE RETARDED CRACK CASE
      XCR=XCR1
      IF (KNT.EQ.0) XCR=CRACK
      IF (KNT.EQ.0) XCR1=CRACK
      KNT=1
      XAOB=AOB
      XRCY=RCY
      XDN=DADN
      XDUM=DUM1
      XDCR=2.0*XRCY*XDN*XDUM*XAOB
      XCR=XCR+XDCR
      IF (KNT1.EQ.1) XCR1=XCR
      DCRACK=XDCR
      CRACK=XCR
      RETURN
      END
```

```
      SUBROUTINE FINLDS
      COMMON SMININ(1000),SMAXIN(1000),CYCIN(1000),COND(1000),INDEX(10),
     1SMULT(10),NLARS(10),SMIN(1000),SMAX(1000),CYC(1000),DELS(1000),TWO
     2A(10),TABA(3000,14),TABB(14,6),MOVER,NCOND,MSETS,XCYC,T,AOB,FYS,KC
     3,KIC,SF,PHISQ,EXM(14),NTWOA,JCNT,ALFA,C,J,IPASS,CRACK,DELK,SRATIO,
     4WIDTH,BOT,ETA,DADN,ICHK,LIO,KEY1,KEY2,KEY3,KEY4,KEY5,KEY6,KEY7,K12
      COMMON K13,K17,ISEG(1000),RATEN(1000),AM(11),HUM,K14,K15,IPROB,RR(
     11000),K8,K9,K16,DEK(10,20),DEDN(10,20),MD1,MD2,MD3,MD4,MD5,MD6,MD7
     2,MD8,MD9,MD(10),IMD,NRTD,DDDA,DUM1,E1,ARY1,DUM3,ARY2,AK1,RY1,RY2,K
     3A9,KEY,K10,DRY,WET,JWD,KCC,INDX,ICYC,ITWOA,CYCTD,TIMTD,INX,AREF,GM
     4AX,GMIN,PTITLE(3,16),LTITLE(2,16),LJOB,LDECK,IJOB,IDECK,K11,IERR,I
     5S(12),STMAX,STMIN,NRD,NSTCDS,XFACT,IQ(1000),NA
C THIS SUBROUTINE WILL LOCATE THE CORRECT LOADS LIB. ON DISK UNIT 9
      IERR=0
10    READ (9,END=20) IJOB,IDECK
C CHECK TO SEE IF JOB & DECK NOS. MATCH THE DESIRED ONES
      IF (IJOB.EQ.LJOB.AND.IDECK.EQ.LDECK) GO TO 30
C IF THEY DO NOT MATCH,GO TO FIRST CARD OF NEXT LIBRARY
      READ (9)
      READ (9)
      READ (9)
      GO TO 10
20    WRITE (6,40) LJOB,LDECK
      IERR=800
      REWIND 9
      RETURN
C IF THEY DO MATCH ,READ THE LOADS LIBRARY
30    READ (9) ((LTITLE(I,K),K=1,16),I=1,2)
      READ (9) NCOND,(NLARS(L),L=1,NCOND),JCNT
      READ (9) (COND(M),SMININ(M),SMAXIN(M),CYCIN(M),RATEN(M),M=1,JCNT)
      RETURN
C
C
40    FORMAT (' THE FOLLOWING LOADS LIBRARY IS NOT LOADED'/10X,2I8)
      END
```

```
      SUBROUTINE RLOADS
      COMMON SMININ(1000),SMAXIN(1000),CYCIN(1000),COND(1000),INDEX(10),
     1SMULT(10),NLARS(10),SMIN(1000),SMAX(1000),CYC(1000),DELS(1000),TWO
     2A(10),TABA(3000,14),TABB(14,6),MOVER,NCOND,MSETS,XCYC,T,AOB,FYS,KC
     3,KIC,SF,PHISQ,EXM(14),NTWOA,JCNT,ALFA,C,J,IPASS,CRACK,DELK,SRATIO,
     4WIDTH,BOT,ETA,DADN,ICHK,LIO,KEY1,KEY2,KEY3,KEY4,KEY5,KEY6,KEY7,K12
      COMMON K13,K17,ISEG(1000),RATEN(1000),AM(11),HUM,K14,K15,IPROB,RR(
     11000),K8,K9,K16,DEK(10,20),DEDN(10,20),MD1,MD2,MD3,MD4,MD5,MD6,MD7
     2,MD8,MD9,MD(10),IMD,NRTD,DDDA,DUM1,E1,ARY1,DUM3,ARY2,AK1,RY1,RY2,K
     3A9,KEY,K10,DRY,WET,JWD,KCC,INDX,ICYC,ITWOA,CYCTD,TIMTD,INX,AREF,GM
     4AX,GMIN,PTITLE(3,16),LTITLE(2,16),LJOB,LDECK,IJOB,IDECK,K11,IERR,I
     5S(12),STMAX,STMIN,NRD,NSTCDS,XFACT,IQ(1000),NA
C     THIS SUBROUTINE READS THE LOADS LIBRARIES AND STORES THE DATA
C     ON DISK UNIT 9
      IJOB=IS(1)
      IDECK=IS(3)
      WRITE (6,50) IJOB,IDECK
      READ (5,60) (PTITLE(2,I),I=1,16)
      JT=JCNT
      WRITE (9) IJOB,IDECK
      READ (5,70) NCOND,(NLARS(I),I=1,NCOND)
C     EACH OF THE SPECTRUM ARRAYS IS LIMITED TO 3000 ELEMENTS.
C     A CHECK IS NOW PERFORMED ON THAT DIMENSION.
C
C
C     THE SPECTRUM IS NOW READ IN. CONDITION IDENTIFICATION
C     IS STORED IN COND(I), STRESSES ARE STORED IN INITIAL
C     ARRAYS SMININ(I) AND SMAXIN(I), INITIAL CYCLES ARE
      STORED IN CYCIN(I).

      JCNT=0
      DO 20 I=1,NCOND
      INDEX(I)=JCNT+NLARS(I)
      JCNT=INDEX(I)
      IF (3000-JCNT) 10,20,20
10    WRITE (6,80)
      CALL EXIT
20    CONTINUE
      KA=1
      DO 40 L=1,NCOND
      KB=INDEX(L)
      DO 30 I=KA,KB
      READ (5,90) COND(I),SMININ(I),SMAXIN(I),CYCIN(I),RATEN(I)
30    CONTINUE
      KA=KB+1
40    CONTINUE
      WRITE (9) ((PTITLE(I,K),K=1,16),I=1,2)
      WRITE (9) NCOND,(NLARS(L),L=1,NCOND),KB
      WRITE (9) (COND(M),SMININ(M),SMAXIN(M),CYCIN(M),RATEN(M),M=1,KB)
      RETURN
C
C
50    FORMAT (' IJOB =',I8,4X,'IDECK =',I4)
60    FORMAT (16A4)
70    FORMAT (11I5)
80    FORMAT (1H0,' THE MAXIMUM NUMBER OF LAYERS HAS BEEN
```

```
     1EXCEEDED.'/1H ,'THE PROBLEM HAS BEEN TERMINATED.')                  RLDS0570
90    FORMAT (A4,2F8.0,F10.0,10X,F10.0)                                   RLDS0580
      END                                                                 RLDS0590
```

```
      SUBRCUTINE PLOTR                                                  PLOT0010
      CCMMON SMININ(1000),SMAXIN(1000),CYCIN(1000),COND(1000),INDEX(10),PLOT0020
     1SMULT(10),NLARS(10),SMIN(1000),SMAX(1000),CYC(1000),DELS(1000),TWOPLOT0030
     2A(10),TABA(3000,14),TABB(14,6),MOVER,NCOND,MSETS,XCYC,T,AOB,FYS,KCPLOT004
     3,KIC,SF,PHISQ,EXM(14),NTWOA,JCNT,ALFA,C,J,IPASS,CRACK,DELK,SRATIO,PLOT0050
     4WIDTH,BOT,ETA,DADN,ICHK,LIO,KEY1,KEY2,KEY3,KEY4,KEY5,KEY6,KEY7,K12PLOT0060
      COMMON K13,K17,ISEG(1000),RATEN(1000),AM(11),HUM,K14,K15,IPROB,RR(PLOT0070
     11000),K8,K9,K16,DEK(10,20),DEDN(10,20),MD1,MD2,MD3,MD4,MD5,MD6,MD7PLOT0080
     2,MD8,MD9,MD(10),IMD,NRTD,DDDA,DUM1,E1,ARY1,DUM3,ARY2,AK1,RY1,RY2,KPLOT0090
     3A9,KEY,K10,DRY,WET,JWD,KCC,INDX,ICYC,ITWOA,CYCTD,TIMTD,INX,AREF,GMPLOT0100
     4AX,GMIN,PTITLE(3,16),LTITLE(2,16),LJOB,LDECK,IJOB,IDECK,K11,IERR,IPLOT0110
     5S(12),STMAX,STMIN,NRD,NSTCDS,XFACT,IQ(1000),NA                    PLOT0120
      DIMENSION CPNAME(12), MP(14)                                      PLOT0130
      EXTERNAL TABL1V                                                   PLOT0140
      IERR=0                                                            PLOT0150
      CKMX=0                                                            PLOT0160
      XN=8.0                                                            PLOT0161
      DO 10 I=1,MSETS                                                   PLOT0170
      MNP=TABB(I,2)-1                                                   PLOT0180
      MP(I)=MNP                                                         PLOT0190
      CKM=TABA(MNP,I)                                                   PLOT0200
      IF (CKMX.LT.CKM) CKMX=CKM                                         PLOT0210
   10 CONTINUE                                                          PLOT0220
      MNP=MP(1)                                                         PLOT0230
      XL=0.0                                                            PLOT0240
      XR=MNP                                                            PLOT0250
      YB=TWOA(1)                                                        PLOT0260
      YT=CKMX                                                           PLOT0270
      CALL STOPTV                                                       PLOT0280
      CALL BRITEV                                                       PLOT0290
      CALL CAMRAV (9)                                                   PLOT0300
      CALL DXDYV (1,XL,XR,DX,N,I,NX,XN,IERR)                            PLOT0310
      IF (IERR.NE.0) GO TO 20                                           PLOT0320
      CALL DXDYV (2,YB,YT,DY,M,J,NY,XN,IERR)                            PLOT0330
      IF (IERR.EQ.0) GO TO 30                                           PLOT0340
   20 WRITE (6,80)                                                      PLOT0350
      RETURN                                                            PLOT0360
   30 CONTINUE                                                          PLOT0370
      CALL GRID1V (1,XL,XR,YB,YT,DX,DY,N,M,I,J,NX,NY)                   PLOT0380
      CALL CHSIZV (3,3)                                                 PLOT0390
      CALL RITE2V (300,10,1023,90,1,16,1,'NUMBER OF BLOCKS',NLAST)      PLOT0400
      DO 40 KK=1,12                                                     PLOT0410
      CPNAME(KK)=PTITLE(1,KK)                                           PLOT0420
   40 CONTINUE                                                          PLOT0430
      CALL RITE2V (50,1011,1023,90,1,48,1,CPNAME,NLAST)                 PLOT0440
      CALL RITE2V (10,250,1023,180,1,21,1,'CRACK LENGTH (INCHES)',NLAST)PLOT0450
      KH=60+(MSETS*26)                                                  PLOT0460
      CALL CHSIZV (2,2)                                                 PLOT0470
      DO 50 L2=1,MSETS                                                  PLOT0480
      KH=KH-26                                                          PLOT0490
      MARK=16+L2                                                        PLOT0500
      IF (MARK.GT.25) MARK=MARK+7                                       PLOT0510
      CALL PLOTV (826,KH,MARK)                                          PLOT0520
      CALL PLOTV (826,KH,MARK)                                          PLOT0530
      CALL RITE2V (880,KH,1023,90,2,3,1,'M =',NLAST)                    PLOT0540
      EMXP=EXM(L2)                                                      PLOT0550
```

```
      CALL LABLV (EMXP,952,KH,4,2,2)                                    PLOT0560
50    CONTINUE                                                          PLOT0570
      DO 70 L2=1,MSETS                                                  PLOT0580
      JENDP=MP(L2)                                                      PLOT0590
      XP1=0                                                             PLOT0600
      YP1=TWOA(1)                                                       PLOT0610
      XP2=1                                                             PLOT0620
      YP2=TABA(1,L2)                                                    PLOT0630
      NX1=NXV(XP1)                                                      PLOT0640
      NY1=NYV(YP1)                                                      PLOT0650
      NX2=NXV(XP2)                                                      PLOT0660
      NY2=NYV(YP2)                                                      PLOT0670
      CALL LINEV (NX1,NY1,NX2,NY2)                                      PLOT0680
      DO 60 J=2,JENDP                                                   PLOT0690
      XP3=J                                                             PLOT0700
      YP3=TABA(J,L2)                                                    PLOT0710
      NX1=NX2                                                           PLOT0720
      NY1=NY2                                                           PLOT0730
      NX2=NXV(XP3)                                                      PLOT0740
      NY2=NYV(YP3)                                                      PLOT0750
      CALL LINEV (NX1,NY1,NX2,NY2)                                      PLOT0760
60    CONTINUE                                                          PLOT0770
      MARK=16+L2                                                        PLOT0780
      IF (MARK.GT.25) MARK=MARK+7                                       PLOT0790
      CALL PLOTV (NX2,NY2,MARK)                                         PLOT0800
      CALL PLOTV (NX2,NY2,MARK)                                         PLOT0810
70    CONTINUE                                                          PLOT0820
      RETURN                                                            PLOT0830
                                                                        PLOT0840
                                                                        PLOT0850
80    FORMAT (' THIS GRID IS IMPOSSIBLE TO PLOT')                       PLOT0860
      END                                                               PLOT0870
```

```
      SUBROUTINE RANGEN (KR1,KR2)
      COMMON SMININ(1000),SMAXIN(1000),CYCIN(1000),COND(1000),INDEX(10),
     1SMULT(10),NLARS(10),SMIN(1000),SMAX(1000),CYC(1000),DELS(1000),TWO
     2A(10),TABA(3000,14),TABB(14,6),MOVER,NCOND,MSETS,XCYC,T,AOB,FYS,KC
     3,KIC,SF,PHISQ,EXM(14),NTWOA,JCNT,ALFA,C,J,IPASS,CRACK,DELK,SRATIO,
     4WIDTH,BOT,ETA,DADN,ICHK,LIO,KEY1,KEY2,KEY3,KEY4,KEY5,KEY6,KEY7,K12
      COMMON K13,K17,ISEG(1000),RATEN(1000),AM(11),HUM,K14,K15,IPROB,RR(
     11000),K8,K9,K16,DEK(10,20),DEDN(10,20),MD1,MD2,MD3,MD4,MD5,MD6,MD7
     2,MD8,MD9,MD(10),IMD,NRTD,DDDA,DUM1,E1,ARY1,DUM3,ARY2,AK1,RY1,RY2,K
     3A9,KEY,K10,DRY,WET,JWD,KCC,INDX,ICYC,ITWOA,CYCTD,TIMTD,INX,AREF,GM
     4AX,GMIN,PTITLE(3,16),LTITLE(2,16),LJOB,LDECK,IJOB,IDECK,K11,IERR,I
     5S(12),STMAX,STMIN,NRD,NSTCDS,XFACT,IQ(1000),NA
C     THIS SUBROUTING PUTS INPUT LOADS IN RANDOM ORDER
      IF (NSTCDS.EQ.1) CALL RINT (KR1,KR2)
      DO 30 I=1,JCNT
10    CALL RAND (U)
      ISEG(I)=ABS(U*(JCNT+1))
      IF (ISEG(I).GT.JCNT.OR.ISEG(I).LT.1) GO TO 10
      IF (I.EQ.1) GO TO 30
      JA=I-1
      DO 20 K=1,JA
      IF (ISEG(I).EQ.ISEG(K)) GO TO 10
20    CONTINUE
30    CONTINUE
      WRITE (6,110)
      IF (KEY3.EQ.0) GO TO 40
      WRITE (6,120)
      GO TO 50
40    WRITE (6,130)
50    CONTINUE
      KAT=45
      DO 80 I=1,JCNT
      L=ISEG(I)
      WRITE (6,140) SMININ(I),SMAXIN(I),CYCIN(I),RATEN(I),SMIN(L),SMAX(L
     1),CYC(L),RATEN(L),DELS(L),L
      IF (I.LT.KAT) GO TO 80
      WRITE (6,110)
      IF (KEY3.EQ.0) GO TO 60
      WRITE (6,120)
      GO TO 70
60    WRITE (6,130)
70    KAT=KAT+45
80    CONTINUE
C     CONTINUE
      IF (KEY4.EQ.3) GO TO 100
      N=1
      WRITE (7,150) (LTITLE(1,K),K=1,16),N
      N=N+1
      WRITE (7,150) (LTITLE(2,K),K=1,16),N
      N=N+1
      WRITE (7,160) JCNT,N
      DO 90 I=1,JCNT
      N=N+1
      L=ISEG(I)
      WRITE (7,170) COND(L),SMIN(L),SMAX(L),CYC(L),RATEN(L),L,N
90    CONTINUE
```

```
100    CONTINUE                                                              RAND0570
       RETURN                                                                RAND0580
C                                                                            RAND0590
110    FORMAT (1H1,13X,'AS READ',29X,'AS REARRANGED'/1X,32('*'),3X,42('*'RAND0600
      1))                                                                    RAND0610
120    FORMAT ('     SMEAN     SALT   CYCLES   RATE    SMIN    SMAX   CYCLERAND0620
      1S   RATE   DEL S   LL'//)                                             RAND0630
130    FORMAT ('      SMIN     SMAX   CYCLES   RATE    SMIN    SMAX   CYCLERAND0640
      1S   RATE   DEL S   LL'//)                                             RAND0650
140    FORMAT (1X,2F8.2,F9.1,F7.1,2F8.2,F9.1,F7.1,F8.2,I5)                   RAND0660
150    FORMAT (16A4,11X,I4)                                                  RAND0670
160    FORMAT ('     1',I5,65X,I4)                                           RAND0680
170    FORMAT (A4,2F8.3,F10.3,10X,F10.2,I10,15X,I4)                          RAND0690
       END                                                                   RAND0700
```

INSTRUCTIONS TO CUSTOMER
IBM 360 PROCEDURE TD9

I. PROGRAM PURPOSE

Procedure TD9 calculates the crack propagation as a function of stress, environment, and material properties. The loading spectra are input as library data, and the environmental data and material properties of the structural member are input as problem data.

II. PRODUCTION SERVICE

The steps to follow for having problem solutions run on the computer at the Fort Worth Division of General Dynamics are described in the document "Utilization of Digital Computing Laboratory Production Services." In general three items are required to obtain this service: (1) production authorization, (2) job sheet, and (3) data tabulation.

III. INPUT DATA

Input data shall be tabulated on standard 80-column data sheets. Columns 67-79 of each card must be tabulated in the following way. Columns 67-72 will contain a 6 digit job number which can be obtained from the computing laboratory at the time the job is submitted. Column 73 will contain either the letter

P or the letter L depending on whether the deck is a problem or library deck. Columns 74-75 contain the deck number and columns 76-79 contain the sequence number of each card within a deck. The first card of each deck must have 0001 in these columns, and each card thereafter must be numbered sequentially.

Description of the input data to be punched on each card is given in the following section. Input quantities must be in the columns noted. A quantity entered as a real number must contain a decimal point. Integer quantities must not contain a decimal and must be entered right-adjusted in their designated columns. Unless otherwise noted variables beginning with I-N are integers and all others are real.

A. Library Deck

Card Type One

Column	Variable	Definition
1-60	TITLE	60 alphanumeric characters used to describe the loads spectrum.

Note: Two (2) cards of card type one will be input for each library.

Card Type Two

Column	Variable	Definition
1-5	NCOND	Number of conditions in library (10 maximum)

Column	Variable	Definition
6-10	NLARS(1)	The number of layers or load
11-15	NLARS(2)	levels for each condition (1 to 10 conditions) (integers)
51-55	NLARS(10)	

Card Type Three

Column	Variable	Definition
1-4	COND(I)	4 alphanumeric characters may be used to identify condition
5-12	SMININ(I)	Minimum load or mean load depending on whether library is min-max or mean-alternating
13-20	SMAXIN(I)	Maximum load or alternating load depending on whether library is min-max or mean-alternating
21-30	CYCIN(I)	The number of applied cycles of the particular load level
31-40	TIMEIN(I)	The amount of time in minutes that a static load is maintained
41-50	RATEN(I)	The rate at which cyclic loads are applied in cycles per minute.

Note: Card type three (3) will be repeated until one card has been read for each layer of each condition. (2000 cards maximum)

B. Problem Deck

Card Type One

Column	Variable	Definition
1-60	PTITLE	60 alphanumeric characters used to describe the problem

Note: Three (3) cards of card type one will be input for problem identification

Card Type Two

Column	Variable	Definition
1-2	KEY1	(KEY1 = 0) A finite width plate (KEY1 = 1) An infinite width plate
3-4	KEY2	(KEY2 = 0) No preload (KEY2 = 1) Proof test preload entered prior to spectrum application
5-6	KEY3	(KEY3 = 0) Minimum and maximum loads in library, (KEY3 = 1) Mean and alternating loads in library
7-8	KEY4	(KEY4 = 0) Loads applied in sequence as input, (KEY4 = 1) Dels (max-min) Loads arranged in ascending order, (KEY4 = 2) Dels (max-min) Loads arranged in descending order, (KEY4 = 3) Loads applied in random order, (KEY4 = 4) Loads applied in random order and new library is punched.
9-10	KEY5	(KEY5 = 0) Intermediate output will print calculations for each layer, (KEY5 = 1) Normal output
11-12	KEY6	(KEY6 = 0) General Dynamics M_k curves used, (KEY6 = 1) Boeing or other M_k data must be entered (see card type 15), (KEY6 = 2) Boeing M_k data for a/2C = 0.5 will be used automatically
13-14	KEY7	(KEY7 = 0) 50% humidity and/or JP4, (KEY7 = 1) 90% humidity and/or JP4, (KEY7 = 2) 50% humidity and/or distilled water, (KEY7 = 3) 90% humidity and/or distilled water

Card Type Two (cont'd)

Column	Variable	Definition
15-16	K8	(K8 = 0) One environment used in this problem, (K8 = 1) Percentages of wet and dry environment used, (K8 = 2) Percentages of wet, dry humidity environment data used.
17-18	K9	(K9 = 1) Dry dadn data, (K9 = 2) Dadn vs delta k data must be input for 3 stress ratios and 3 cyclic loading rates, (K9 = 3) Humidity dadn data, (K9 = 4) Regular JP4 or distilled water dadn data used, (K9 = 5) Other dadn data must be read (see card types 13 and 14)
19-20	K10	(K10 = 0) Basic delta k equation used, (K10 = 1) Data read to modify delta k for a crack initiating in a hole (see card type 12)
21-22	K11	(K11 = 0) Basic loads used, (K11 = 1) Stress gradient will be read for stress as a function of crack depth (see cary type 3)
23-24	K12	(K12 = 0) Basic loading order, (K12 = 1) First ILR load levels will be repeated NPAS times in each pass (see card type 7)
25-26	K13	(K13 = 1) Printed output, (K13 = 2) Microfilm output, (K13 = 3) Printed & microfilm output
27-28	K14	(K14 = 0) Basic loading order, (K14 = 1) Make up flight beginning load levels will be entered for make up flights 2, 3, and 4. One make up flight will be applied at the end of each pass (see card type 6)
29-30	K15	(K15 = 0) No plots, (K15 = 1) Output will be plotted
31-32	K16	(K16 = 0) 1 Set of stress factors for multiple conditions, (K16 = 1) 1 Condition with MSETS different stress factors and crack growth curves.

Card Type Two (Cont'd)

Column	Variable	Definition
33-34	K17	(K17 = 0) Basic procedure) (K17 = 1) Alternate randomizations obtained for each MSETS (KEY4 must be 3 or 4)
35-36	K18	(K18 = 0) Plane strain (P_f=f(6 PI) (K18 = 1) Plane stress (P_f=f(2 PI) P_f = retardation plastic front

Card Type Three

Column	Variable	Definition
1-6	LJOB	Job number of loads library to be used in this problem.
9-10	LDECK	Deck number of loads library to be used in this problem.
11-20	T	Thickness of part
21-30	TWOA (1)	Initial crack length
31-40	STMAX	Maximum stress factor for stress gradient case (used when K11 = 1)
41-50	STMIN	Minimum stress factor for stress gradient case (used when K11 = 1)
51-60	WIDTH	Part width if finite

Card Type Four

Column	Variable	Definition
1-10	AOB	Half of crack surface length divided by crack depth
11-20	PHISQ	Phi squared - a constant which is a function of crack shape
21-30	DRY	Portion of time dry environment is used for multiple environment case (K8 = 1 or 2)

Card Type Four (Cont'd)

Column	Variable	Definition
31-40	WET	Portion of time water environment is used for multiple environment case (K8 = 1 or 2)
41-50	HUM	Portion of time humidity environment is used for triple environment case (K8 = 2)
51-60	NRTD	(NRTD = 0) Retardation used (NRTD = 1) No retardation (NRTD = 3) Cycle by cycle analysis

Card Type Five

Column	Variable	Definition
1-10	FYS	Yield stress in ksi
11-20	RKC	Stress intensity cutoff (.9 KC causes problem to terminate)
21-30	RKIC	Stress intensity cutoff (.9 KIC causes problem to terminate)
31-40	CYCTD	Cyclic delta k threshold (no crack growth below this level)
41-50	TIMTD	Static load delta k threshold (no crack growth below this level)
51-60	BLK	Block factor for punched output BLK = block hours/200

Card Type Six

Column	Variable	Definition
1-10	XCYC	Cyclic multiplier
11-15	ISF	Number of passes or applications of loads spectrum (1000 maximum)

Card Type Six (Cont'd)

Column	Variable	Definition
16-20	L10	Problem number on cards if punched output is obtained (punched when $10 \leq L10 < 100$)
21-25	IPROB	Sequence number on first card if punched output is given
26-30	M2	First load level of make-up flight 2 (used when K14 = 1)
31-35	M3	First load level of make-up flight 3 (used when K14 = 1)
41-50	RESID1	Residual stress in ksi
51-60	RESID2	Residual stress in ksi for stress gradient case (if gradient is used RESID1 must be 0)
61-66	JOB	Job number punched on output cards

Card Type Seven

Column	Variable	Definition
1-5	MSETS	Number of different retardation factors to be used
6-10	NPAS	Number of times first ILR loads to be repeated (used when K12 = 1)
11-15	ILR	Number of load levels to be repeated NPAS times (must be the first load levels in spectrum and used when K12 = 1)
21-30	DIA	Hole diameter for Bowie model crack in a hole (used when K10 = 2)
31-40	FACDA	Constant factor to be applied to da/dN data
41-50	FMAX	Maximum concentration factor allowed with Bowie model.

Card Type Eight

Column	Variable	Definition
1-10	SMAX	Preload stress, ksi (entered if K2 = 1)

NOTE: If (KEY2 = 0) card type eight (8) is omitted.

NOTE: Card types nine (9), ten (10), and eleven (11) are used only when (K9 = 2).

Card Type Nine

Column	Variable	Definition
1-5	MD1	Number of data points on da/dn vs K curve for stress ratio less than .2 and 6 cpm data
6-10	MD2	Number of data points on da/dn vs K curve for stress ratio less than .2 and 60 cpm data
11-15	MD3	Number of data points on da/dn vs K curve for stress ratio less than .2 and 180 cpm data
16-20	MD4	Number of data points on da/dn vs K curve for stress ratio $.2 \leq R < .4$ and 6 cpm data
21-25	MD5	Number of data points on da/dn vs K curve for stress ratio $.2 \leq R < .4$ and 60 cpm data
26-30	MD6	Number of data points on da/dn vs K curve for stress ratio $.2 \leq R < .4$ and 180 cpm data
31-35	MD7	Number of data points on da/dn vs K curve for $R \geq .4$ and 6 cpm data
36-40	MD8	Number of data points on da/dn vs K curve for $R \geq .4$ and 60 cpm data

Card Type Nine (Cont'd)

Column	Variable	Definition
41-45	MD9	Number of data points on da/dn vs K curve for R > .4 and 180 cpm data

Card Type Ten

Column	Variable	Definition
1-5 6-10 11-15 . . . 45-50	DEDN(1,M)	Da/dn points along curve corresponding to MD1 (MD1 points must be entered - M=1, MD1)

Card Type Eleven

Column	Variable	Definition
1-5 6-10 . . . 45-50	DEK(1,M)	Delta K points along curve corresponding to MD1 (MD1 points must be entered - M=1, MD1)

NOTE: One card type eleven (11) and nine sets of cards with each set containing one card type twelve (12) and one card type thirteen (13) will be entered. The curves for MD1 - MD9 are read in order.

NOTE: Card type twelve (12) is entered only if (K10 = 1).

Card Type Twelve

Column	Variable	Definition
1-10	GMAX	Maximum K multiple

Card Type Twelve (Cont'd)

Column	Variable	Definition
11-20	GMIN	Minimum K multiple
21-30	AREF	Crack length at which 99% of difference between GMAX and GMIN is attained.

NOTE: Card type thirteen (13) is entered only if (KEY6 = 1). If (KEY6 = 0) Boeing a/2c = 0.5 M_k data will be used.

Card Type Thirteen
(Used when K9 = 5)

Column	Variable	Definition
1-5	IPF	IPF = 0 for Paris equation IPF = 1 for Forman equation
6-10	NRC	Number of R values for which dadn data is entered (NRC = 1 for Forman equation and NRC_{max} = 3)
11-50	DADNID	40 alphanumeric characters to describe dadn data
51-55 56-60 61-65	RVAL	Number of line segments used to define dadn data for each R value

Card Type Fourteen
(Used when K9 = 5)

Column	Variable	Definition
1-10	DACON	C value used in dadn equation--C*ΔK**N
11-15	DSLOPE	N value in dadn equation
16-20	DKMAX	Maximum ΔK for which this line segment of dadn curve is used

Card Type Fourteen (Cont'd)

Column	Variable	Definition
21-30 31-35 36-40	DACON DSLOPE DKMAX	Same as columns 1-20 except for another segment of dadn data
41-50 51-55 55-60	DACON DSLOPE DKMAX	Same as columns 1-20 except for another segment of dadn data
61-65	RVAL	Kc if Forman equation used (IPF=1) R if Paris equation used (IPF=0) R equals min stress divided by max stress

NOTE: Card 14 will be repeated NRC times, and each card will have RVAL(I) line segments to define the dadn data.

Card Type Fifteen

Column	Variable	Definition
1-5	AM(I)	I = 1,11
6-10 . . 51-55		M_k points are read as a function of BOT (crack depth/thickness) for BOT values of 0, .1, .2, ... 1.0

Card Type Sixteen

Column	Variable	Definition
1-5	SMULT(M)	M = 1, NCOND
6-10 . . 45-50		Stress factors are read for each condition. SMULT times load gives stress in ksi (10 is maximum NCOND)
56-60 61-65	KR1 KR2	Constants used to begin calculation of random numbers

Card Type Seventeen

Column	Variable	Definition
1-5	EXM(M)	M = 1, MSETS
6-10		retardation factors to be used in
7-15		this problem (maximum of 14)
.		
.		
55-60		

IV. OUTPUT DATA

All printed output data is identified with headings that are self-explanatory. Punched card output can be obtained by using the variable LIO in card type six (6). This output gives the crack length and flight hours for problems with 200 hour blocks.

V. TIME ESTIMATE

Procedure TD9 takes approximately 1.5 minutes to load and then the execution will require less than 1.0 minute for each million cycles.

VI. ERROR MESSAGES

Procedure TD9 has built in checks that will cause a problem to terminate. If any of these checks find an error, an explanation of the error will be given on the computer output and the next problem will be attempted.

VI.5 UNIT STRESS CONCEPT

The unit stress concept (stress per unit of load) provided an expeditious method of relating stress at a point to applied load. For fatigue (and crack growth) analysis, a stress spectrum is required which will reflect tensile stresses experienced by both upper and lower wing surfaces.

The lower wing surface is in tension due primarily to positive flight maneuvers (wing tip up) while the upper surface is generally in tension during negative flight maneuvers (wing tip down). Design effort was generally concentrated at baseline center spar stations 140 and 340, a typical inboard and outboard area of the wing box respectively.

While the complete baseline fatigue loads spectrum contains bending moments, shears and torsions, the predominate load contributor to the magnitude of stress in critical structure is net bending moment. Therefore, a fatigue loads spectrum for positive and negative maneuvers was prepared in terms of wing bending moment at the <u>pivot</u>. Unit stress coefficients were then developed as a means to transform pivot bending moment to stresses.

The use of <u>pivot</u> bending moment for developing stress coefficients rather than bending moments at the local wing stations assumes that a constant relationship between BM, shear, and torsion exists at any wing station along the span. This relationship does not remain exactly constant in the F-111F wing; but since shear and torsion do not significantly contribute to wing stresses at points considered critical in fatigue and fracture, the assumption was considered valid for analysis during Phase IA just as it was during the F-111 program. If the detail design (and analysis) effort in the follow-on indicates that other load parameters contribute significantly to the stress in a structural element, they will be included.

The actual development of unit stress coefficients was accomplished as follows. A finite element math model was used to develop baseline ultimate stresses for each of the four F-111F static design conditions selected for this program. Two conditions represent positive loading (F400A, F101A), and two represent negative loading (F401A, F702A). Stress distributions for the baseline cross sections at C.S.S. 140 and 340 resulted from this analysis. Stresses for both the upper and lower surfaces were included. Additional discussion of these analyses was given in Section V of Volume I and Appendix V of Volume III.

The maximum cross section stresses for the lower surface occur in the region of the forward auxiliary spar. Maximum stresses for the upper surface occur in the center spar region. These maximum ultimate design stresses for each condition were reduced to limit design stresses (1.5 factor), and "unitized" using the corresponding limit design pivot bending moments. The procedure is illustrated typically below for C.S.S. 140:

<u>F400A</u> (M = 1.05, $\Lambda = 45^{\circ}$, h = 2000', n_Z = 7.33)

$f_{Lim.}$ = 47.5/1.5 = 31.67 KSI (ten. lower surface)

Lim. Pivot BM = 19.52 x 10^6 in. lbs.

$f/10^6$ in.lb. BM_p = 31.67/19.52 = <u>1.622 KSI</u>

<u>F101A</u> (M = 330 KCAS, $\Lambda = 16^{\circ}$, S.L., n_Z = 4.124)

$f_{Lim.}$ = 42.9/1.5 = 28.6 KSI (ten. lower surface)

Lim. Pivot BM = 17.66 x 10^6 in. lbs.

$f/10^6$ in.lb. BM_p = 28.6/17.66 = 1.619 KSI

<u>F-401A</u> (M = 1.05, $\Lambda = 45^{\circ}$, h = 8000', n_Z = - 3.00)

$f_{Lim.}$ = 24.15/1.5 = 16.1 KSI (ten. upper surface)

Lim. Pivot BM = -9.914 x 10^6 in. lb.

$f/10^6$ in.lb. BM_p = 16.1/- 9.914 = - 1.624 KSI

<u>F702A</u> (M = 1.40, $\Lambda = 72.5^{\circ}$, h = 17,500', n_Z = - 3.00)

$f_{Lim.}$ = 21.85/1.5 = 14.57 KSI (ten. upper surface)

Lim. Pivot BM = -8.301 x 10^6 in. lb.

$f/10^6$ in.lb. BM_p = 14.57/- 8.301 = <u>-1.752 KSI</u>

The unit stress coefficients at C.S.S. 340 were developed in an identical manner for comparison. A summary of coefficients is given below for C.S.S. 340 which illustrates that wing load fatigue stresses are relatively low at the outboard wing stations.

F400A

$f/10^6$ in. lb. BM_p = 0.252 KSI

F101A

$f/10^6$ in. lb. BM_p = 0.256 KSI

F401A

$f/10^6$ in. lb. BM_p = 0.124 KSI

F702A

$f/10^6$ in. lb. BM_p = 0.257 KSI

The maximum unit stress coefficient for the C.S.S. 140 lower surface and upper surface was then selected for analysis purposes. The selected coefficients are shown underlined in the preceding summaries.

The baseline unit stresses were adjusted for use with other materials by applying a ratio based on material ultimate strength allowables.

Variation in the basic spectrum of fatigue stresses was accomplished by increasing or decreasing the unit stress coefficients by $\pm$ 10% increments and then multiplying the appropriate pivot bending moment spectrum by the incremented unit stresses. This variation was required to generate the "catalog" of fatigue damage curves discussed in paragraph VI.1.

It should be noted that the maximum positive pivot bending moment occurring in the F-111 baseline fatigue loads spectrum is 15.55×10^6 in. lbs. (occurring in condition 5:M = 0.9, $\Lambda = 72.5^o$, S.L., n_Z = 8.43). This maximum operating load for the baseline is less than design limit. The maximum baseline negative pivot bending moment is $- 3.46 \times 10^6$ in. lb. (Condition 8:M = 0.75, $\Lambda = 26^o$, h = 20,000', n_Z = 1.50), also below design limit load.

The fact that the baseline operating loads (stresses) are less than design limit loads (stresses) led to the decision that all design allowable data would be better presented in terms of "maximum allowable spectrum stress" level, which would correspond to the 15.55×10^6 in.lb. pivot bending moment noted above for the lower surface or the $- 3.46 \times 10^6$ in. lb. pivot

bending moment for the upper surface. This method of identifying the allowable stresses was used throughout Phase IA.

APPENDIX VII

COST ESTIMATION DATA

This appendix contains a discussion of cost estimates as they apply to the various evaluation steps in the program. It is intended to provide a more detailed explanation of cost data which has been generated in support of the Advanced Air Superiority Fighter Wing Structure Program. Information from the baseline cost document is also contained in this appendix.

VII.1 BASELINE COSTS

FZM No. 5990, dated 28 July 1972, titled "Advanced Air Superiority Fighter Wing Structures, Baseline Definition Cost Description" provides the baseline document which defines in detail the costs associated with producing the F-111F wing box. This document identifies a specific aircraft (Unit No. 506) as a point baseline for costs. From this point cost, learning curves were applied to obtain costs for manufactured units Nos. 1, 2, 50, 150, 200, and 800. These costs were generated for a production rate of 20 aircraft per month. The point cost for Unit 506 was obtained from expenses incurred in the fabrication, assembly, material, and outside procurement activities for the production of an F-111F wing during manufacturing Lot No. 20. This lot consisted of 22 F-111F aircraft Nos. 37 through 58 and represents aircraft 495 through 516 in the overall F-111 production program.

Component costs for skins, ribs, spars, etc., were established for the point aircraft only. These costs served to identify the high cost items and indicated where the largest savings could be realized. Figure 65 provides an overview of the basic cost structure which is used by Convair. The information contained in that report has been used as a baseline for this program. As such, it supports the document FZM-5989, Advanced Air Superiority Fighter Structures, Baseline Definition, Structural Description and FZM-6100, Baseline Document for Advanced Air Superiority Fighter Wing Structures have also been submitted.

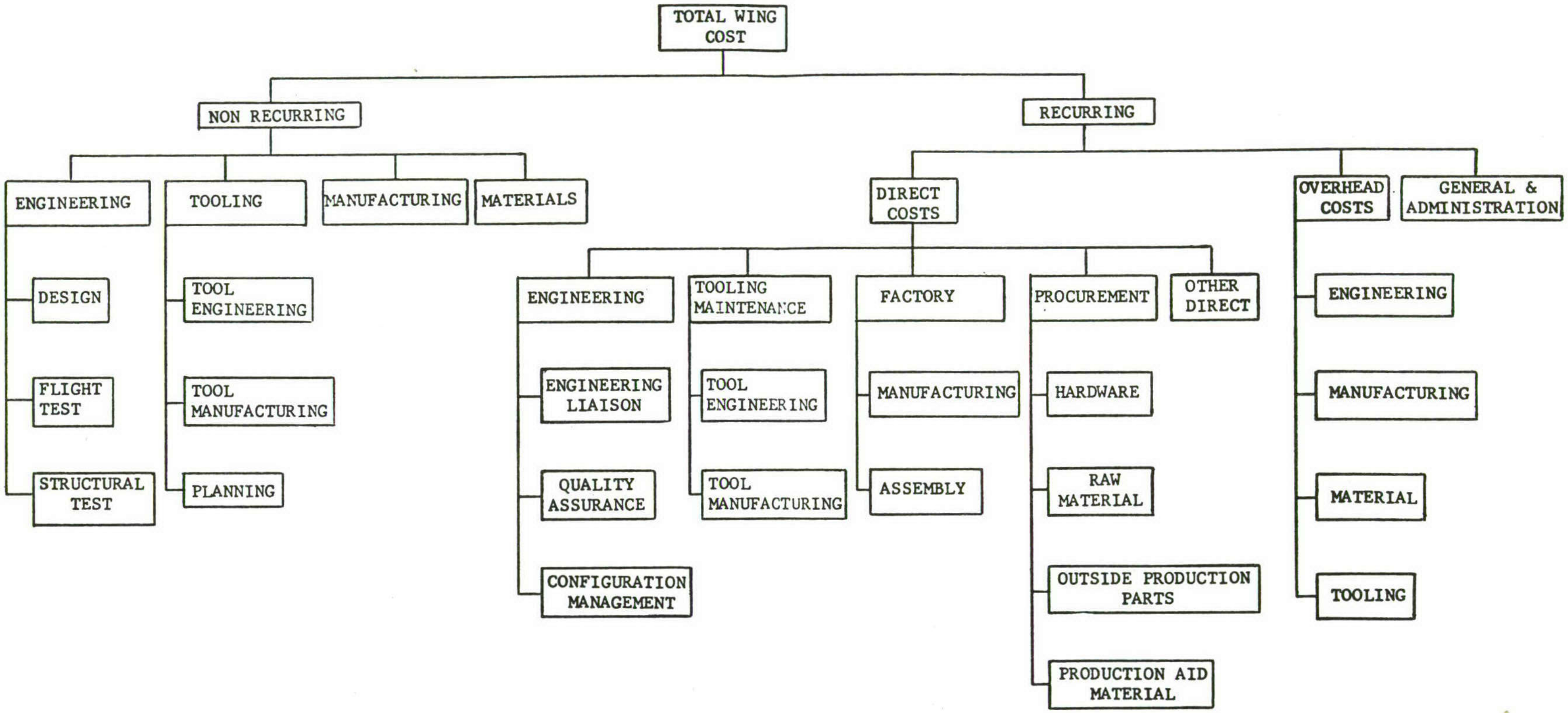


Figure 65 Convair Cost Structure

VII.2 COMPONENT COST BREAKDOWN

A breakdown of cost by general components was provided in the baseline document and is shown in Table XL. Included in the individual component cost is all recurring direct charges for material, fabrication, hardware, installation into the basic wing box, and sealing operations.

These figures are based on the point aircraft at the average production rate actually experienced during the F-111 program.

VII.3 PRODUCTION RATE AND QUANTITIES COST

Costs for production quantities are shown in detail in Table XLII and are plotted in Figure 66. The point aircraft costs for both actual production rate and for 20 aircraft per month are shown in Table XLII to permit cross referencing to Table XL. These two costs for the point aircraft are also shown in Figure 66.

Overhead costs plus General and Administrative charges are shown in Table XLII for information. The curve identified as "TOTAL COST" in Figure 66 includes all Recurring Costs, as defined in Figure 65 while the curve identified as "MANUFACTURING COST" Excludes Overhead and General and Administrative charges.

The point cost generated for F-111 No. 506 was used to establish a stable baseline for comparison. Since the production rate greatly affects the overall cost of a structure, the baseline cost was evaluated to determine the effect of a twenty aircraft per month production rate. The results of this analysis are shown in Table XLII.

The actual F-111 wing costs, projected to a twenty aircraft per month production rate, were used as the baseline cost for this program. A "design to cost" target of $54,640 (15% below baseline) was established as one of the program goals for at least one wing configuration.

VII.4 COST COMPARISONS

Table XLI lists the significant factors included in developing the cost data in this project.

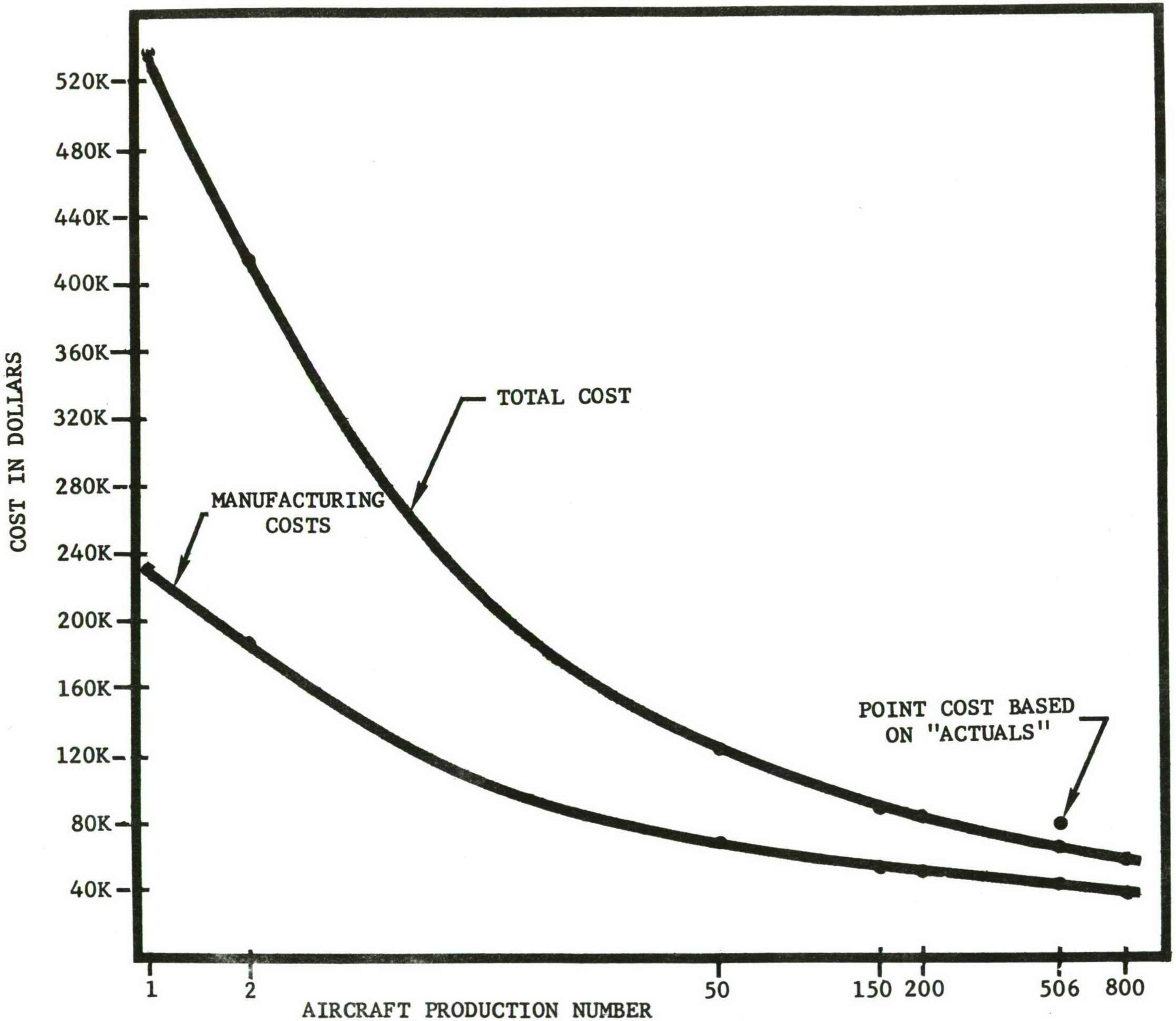


Figure 66 Baseline Cost Curve (Based on 20 Aircraft per Month)

Table XL

F-111 WING BOX COMPONENT COST BREAKDOWN
(Point Baseline, Aircraft 506)

COMPONENT/ACTIVITY	COST
1. Upper Skin	1903.89
2. Lower Skin	3011.75
3. Spars	19803.13
4. Ribs	2825.07
5. Pylons	9023.75
6. Miscellaneous	6072.41
7. Mfg Direct Charges	116
8. Subtotal (1-7	$42,756
9. Engineering	1440
10. Tooling Maintenance	554
11. Other Direct Charges	35
12. Subtotal (9-11)	$ 2,029
13. Overhead	23,665
14. General & Administrative	5,475
15. Subtotal (13 & 14)	$29,140
Total Cost	$73,925

Table XLI
FACTORS USED IN COST COMPARISONS

MATERIAL

Base Price of Material Extras: Length, width, thickness	
Quantity	
Attrition	Extrusions
Freight	Castings
Allocations	Forgings

MANUFACTURING - (FACTORY/FABRICATION/ASSEMBLY)

Fabrication Labor	Metal Removal Rates
Sub-Assembly Labor	Experience/Learning Curve Data
Processing Labor	Experience/Prior History Data
Assembly Labor	Experience/Similar Programs
Quality Assurance	Production Rate (Units Per Time)
	Tooling Concept

TOOLING

Tool Manufacturing Labor	Tool Maintenance
Tool Material	Special Maintenance (Example: Brazing Tooling)
Special Material	
Computer Charges (N.C. Machining)	Tool Planning and Design
Allocations/Other Charges	Manufacturing Engineering
Duplicate Tool Sets (Production Rate)	Limited O.H. Burden

Excluded cost factors include such items as risk, profit and escalation factors.

The following sections numbered VII.5 through VII.11 are in explanation of the source of cost information and cost comparison development.

VII.5 MATERIAL COSTS

The material cost data used in this project has been supplied by Material Department cost estimators. Costs of material were obtained from recent purchase orders, recent quotes from vendors, or, for some of the new material applications, by telephone calls to the mills or suppliers. Costs were developed for the specific material form, size, length, and thickness. Any other "extra" costs involved for that item were also considered. This provided a cost per pound for use in calculations. For new materials, the material cost has been projected on the basis of increased usage.

An attrition factor was developed using prior historical experience and anticipated factory loading to be applied to the material costs. Allocation costs and freight were assigned as a numerical percentage to be applied to material costs.

VII.6 MANUFACTURING COSTS (FACTORY)

All tasks associated with the manufacturing of a product, excluding materials procurement and manufacturing engineering, are factory responsibilities. Therefore, for convenience, the term "factory" is frequently used to describe the labor cost of a product. The labor hours for a given concept were supplied by Industrial Engineering after analysis of the drawings.

Various techniques are used for establishing standards and estimating factory costs. For instance, the amount of metal removed is a key factor in estimating machining operations. In another operation such as bonding, square footage may be the key estimating factor. Welding estimates consider the number of passes and inches of weld.

At Convair, the fabrication, machining, processing, and sub-assembly operations are normally grouped together, and referred to as "Fabrication" while major assembly and final finishing is covered under the term "assembly" operation.

Quality Assurance costs are a factor of manufacturing costs. This factor is added by the Industrial Engineering estimator, after arriving at a manufacturing cost.

The impact of production quantity and schedule is considered in the factory labor estimates. Use of experience curve data, commonly referred to as "learning curve" data, has been applied to all factory estimates. A number one unit manhour estimate is developed, then by use of learning curve factors, an estimate is made for the desired unit cost. An appropriate labor rate is applied to the labor hour estimate to give a dollar value.

VII.7 TOOLING COST

Several terms are used to describe the Manufacturing Engineering function. Often the term "tooling" is applied since it is their task to plan, design, and manufacture the tools needed to manufacture a given product. Further, they plan the detail fabrication, processing, and manufacturing operations of all details, sub-assemblies, and assemblies. Another tooling function is to provide manufacturing engineering "consultants" to the design team to advise them on manufacturing and producibility.

Through evaluation of a given concept, the manufacturing engineer can determine the kind and type of "hard" tools needed to manufacture the product. With this information, an estimate of tool manufacturing hours can be developed using historical tool cost data. With this estimate for hard tooling as a base, additional factors can be applied to provide a complete estimate. Tool maintenance, for example, is one of the factors that can be determined with the tool manufacturing hours as a base cost element.

VII.8 SCHEDULE

The rate of production, or delivery schedule of the product is an important factor of cost. This rate determines the quantity of "Rate" tools required to meet the manufacturing schedule.

To establish the cost of duplicate tools required, a production rate of twenty units per month was established. The actual cost of the F-111F wing was adjusted to reflect the cost improvement anticipated by the improved production rate. The difference in cost is reflected in Table XLII.

GENERAL DYNAMICS
Fort Worth Division
TABULATION SHEET

Table XLII
F-111 WING BOX COST DATA
(DATA IS PER WING 1/2 SHIP SET - BASED ON 20 A/C PER MONTH EXCEPT AS NOTED)

DEPARTMENT 65
FWP 2646-7-64

	UNIT NO. 1		UNIT NO. 2		UNIT NO. 50		UNIT NO. 150		UNIT NO. 200		UNIT NO. 506 (ACTUAL RATE)		UNIT NO. 506 (20 A/C PER MO.)		UNIT NO. 800	
	HOURS	COST	HOURS	COST	HOURS	COST	HOURS	COST	HOURS	COST	HOURS	COST	HOURS	COST	HOURS	COST
A. DIRECT LABOR																
1. Engineering Liaison	416	3128	341	2564	136	1023	99	745	91	684	70	527	70	527	60	459
2. Product Assurance	15	114	12	91	5	38	4	30	3	23	2.5	19	2.5	19	2	15
3. Config. Mgmt.	9	54	7	42	3	18	2	12	2	12	1.5	9	1.5	9	1	6
4. Total Engr. Pool	440	3296	360	2697	144	1079	105	787	96	719	74	555	74	555	63	480
5. Tool Maint. (Engr.)	832	4834	682	3962	272	1580	198	1150	183	1063	140	810	140	810	123	714
6. Tool Maint. (Mfg.)	725	3756	595	3082	237	1228	173	896	159	824	122	630	122	630	107	554
7. Total Tool Maint.	1557	8590	1277	7044	509	2808	371	2046	342	1887	262	1440	262	1440	230	1268
8. Factory	29657	140052	22303	105270	4816	22731	2917	13769	2560	12083	2309	10896	1684	7946	1371	6471
9. Quality Assurance	6258	33981	4704	25543	1016	5517	616	3344	540	2932	486	2644	355	1927	289	1570
10. Total Mfg. Pool	37487	182625	28284	137857	6341	31056	3904	19159	3442	16902	3057	14980	2301	11313	1890	9309
TOTAL DIRECT LABOR		185919		140554		32135		19936		17621		15535		11868		9789
B. OTHER DIRECT CHARGES																
1. Engineering		164		135		54		39		36		28		28		24
2. Product Assurance		9		7		3		2		2		2		2		1
3. Tooling		29		24		10		7		6		5		5		4
4. Manufacturing		687		563		224		164		151		116		116		101
TOTAL DIRECT CHARGES		889		729		291		212		195		151		151		130
C. PROCUREMENT/SUBCONT.																
1. Purchased Parts		15467		14694		11579		10675		10450		9757		9757		9431
2. Raw Material		18641		17709		13955		12866		12595		11758		11758		11367
3. Production Aid		544		446		178		130		119		88		88		80
4. Outside Production		11886		11292		8898		8204		8031		7497		7497		7248
TOTAL PROC./SUBCONT.		46538		44141		34610		31875		31195		29100		29100		28126
TOTAL FABRICATION COSTS		233346		185424		67036		52033		49011		44786		41119		38045
D. OVERHEAD-DIVISION																
1. Engineering	440	3155	360	2581	144	1032	105	753	96	688	74	530	74	530	63	452
2. Manufacturing	37487	260534	28284	196573	6341	44070	3904	27133	3442	23922	3057	21243	2301	15982	1890	13135
3. Material		3020		2869		2250		2072		2027		1891		1891		1828
TOTAL DIV. OVERHEAD		266714		202023		47352		29958		26637		23665		18403		15415
E. GENERAL & ADMIN.		40005		30996		9143		6560		6052		5476		4762		4277
TOTAL COST		540065		418443		123531		88551		81700		73925		64283		57737

VII.9 GRASS ROOTS ESTIMATING METHOD

The "grass roots" estimating technique was used to develop the comparative cost data. A single set of drawings was provided to each functional department representative for use in preparing cost data. The same ground rules, labor rates, etc., were used on the various concepts as were used on the baseline design.

The functional department inputs were received by Value Engineering. In some instances Value Engineering assisted the functional departments in preparing the estimates. From this data, applicable rates and factors were added to give a comparative cost figure for each element, such as a skin or a spar.

This cost, based upon a production cost point of 506, was provided to design for their review against baseline costs and targeted goals. The cost of the details such as skins, spars, hat sections, bolts, adhesive, etc., were made available on a master analytical assembly cost drawing for each of the concepts. The drawing was then left open on a design board in the area.

The data allowed the designer to see the cost impact of the various elements as he continued to analyze his design for alternatives. Further trade studies on various elements were made so that the designer could see the relative cost impact of proposed changes The more cost favorable design approaches could then be adopted prior to the final phase of the program.

VII.10 COSTING LEVELS

The baseline cost document established a ground rule that cost data would not be developed on the element and cross-section concepts phases of the program. Comparison to the baseline was to be on a best estimate basis only.

However, to insure cost integrity in the evaluation of the concepts, it was later determined it would be beneficial to establish cost comparison data for all of the fifty cross section concepts. This effort greatly exceeded the original intent of the program.

All other costing efforts either met or exceeded the costing level efforts as established in the baseline requirements.

VII.11 COSTING GROUNDRULES AND FACTORS

The following ground rules were followed in preparing comparative cost analyses for the selected configurations:

a. Overhead costs for all facets of manufacturing, materials, engineering, and tooling were not included in the cross section and analytical assembly evaluation phases.

b. Additional costs for General and Administrative expenses were not included in the cross section and analytical assembly evaluation phases.

c. During the cross section concept and analytical assembly phases Engineering Liaison costs were not considered in the recurring cost category. However they were projected independently as support for the factory during the manufacturing program for the full wing estimates.

d. Tool maintenance costs were projected in the recurring cost category and listed independently in the final cost breakdown as a separate line item.

e. It was assumed that the Air Force would take control of the tools at the completion of the contract. Therefore, no continuing maintenance and control costs were included for this task.

f. Costs were included for Quality Assurance and Manufacturing Quality Control support during the Engineering and Manufacturing span of the contract.

g. Costs were projected based on labor rates and material charges used for the point baseline cost No attempt was made to incorporate escalating costs due to inflationary factors, etc.

h. Corresponding baseline data costs were determined for comparison purpose in both the cross section and analytical assembly phases of the program.

VII.12 STRUCTURAL DESCRIPTION

Those items included in the baseline wing box are shown in Figure 67. Only the basic wing box was included; the leading edge, trailing edge, tip, and pivot fitting were deleted. Pylon attach points were included, but the components required to rotate them were not included since these would probably not be required on an advanced air superiority fighter. Electrical and fuel equipment were not included.

VII.13 MANUFACTURING SEQUENCE

Manufacturing of the F-111 wing is shown schematically in Figure 68. Those items not included in the baseline are identified. All assembly operations associated with the basic wing box were included in the cost. These include fuel sealing and internal corrosion protection systems required to insure the integrity of the integral fuel tank.

Painting of the external surface was not included since that operation is performed after installation to the aircraft.

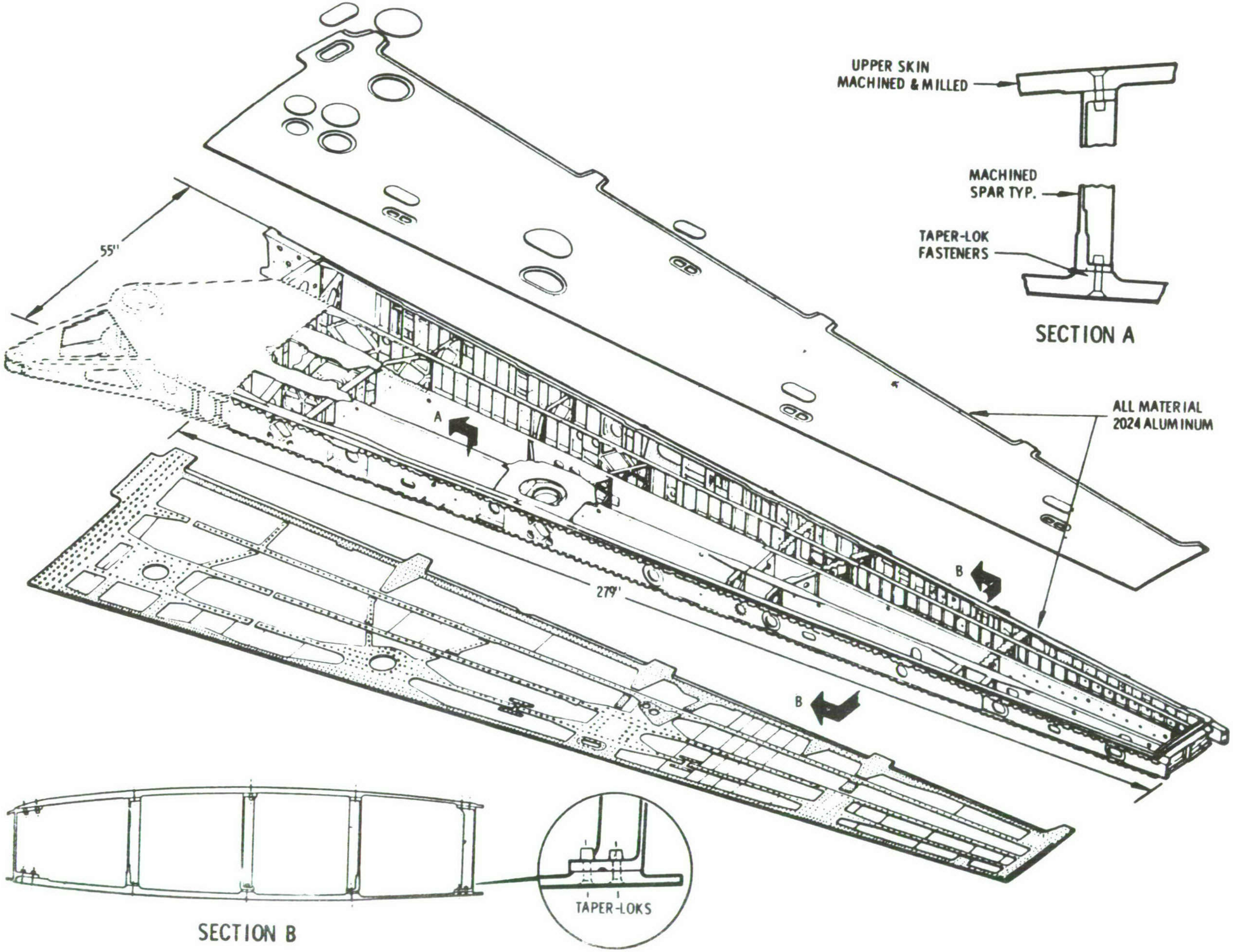
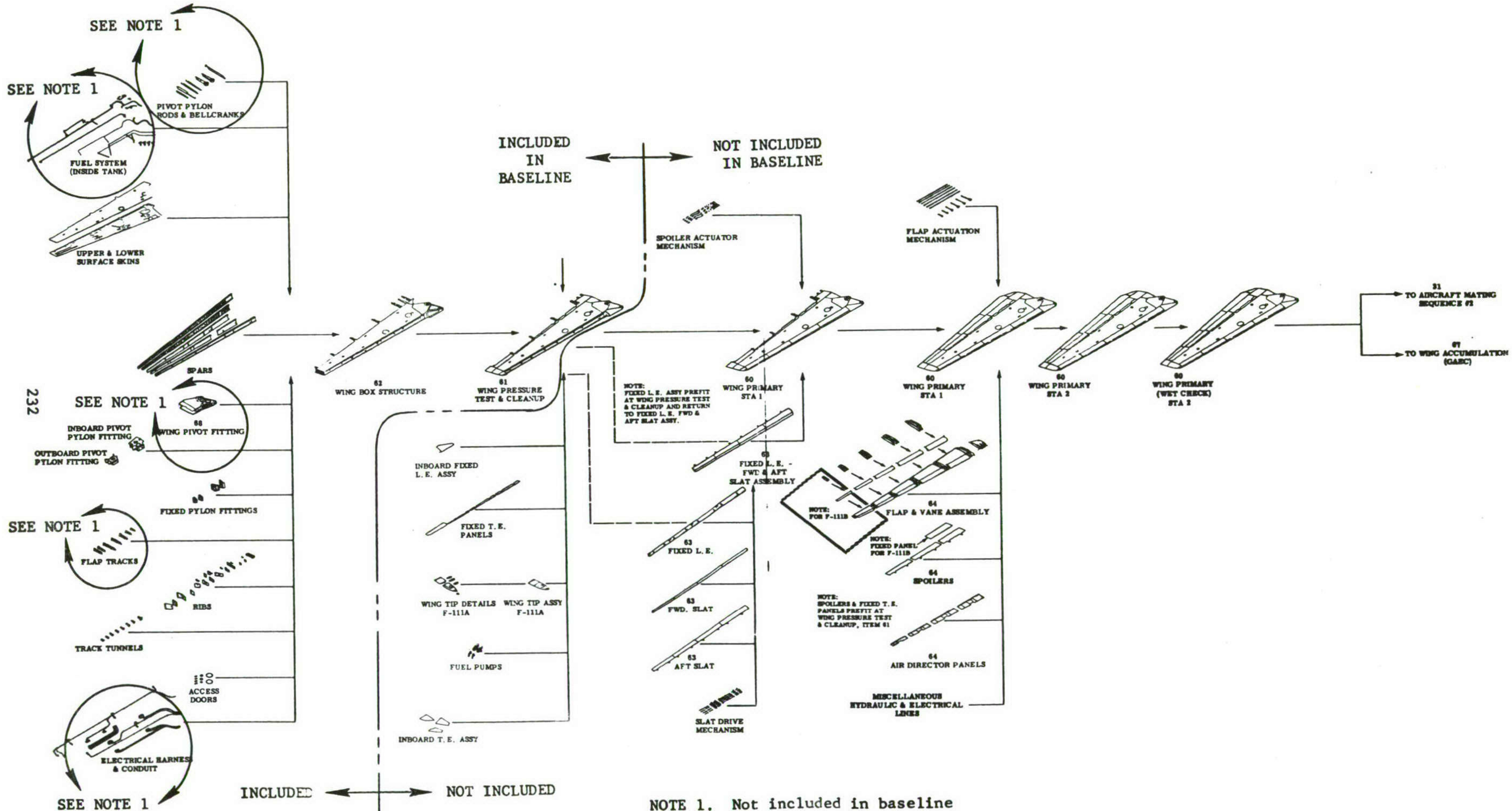


Figure 67 Baseline Wing Box



NOTE 1. Not included in baseline

Figure 68 F-111 Wing Manufacturing Sequence

APPENDIX VIII

MATERIALS TEST PROGRAM DATA

Table XLIII
BASIC PHASE IA MATERIALS TEST PROGRAM

	TYPE OF SPECIMEN		ALUMINUM				TITANIUM	
			7050		7475		8-8-2-3	
			-T76	-T73651	-T761	-T7351		
	Sheet	Plate	Sheet	Plate	Sheet	Plate	Sheet	Plate
• TENSILE STRENGTH YIELD AND ULTIMATE - SEE NOTE 2, 3 & 4	Flat	Round	60	63	6	6	3	6
• COMPRESSIVE STRENGTH YIELD AND ULTIMATE - SEE NOTE 2	Flat	Round	33	33	-	-	-	-
• FRACTURE TOUGHNESS, K_{IC}	-	Comp. Tens.	-	6	-	3	-	6
• STRESS CORROSION K_{ISCC} 2 DIRECTIONS, 4 SPECIMEN/DIRECTION SALT WATER	-	Compact Tension	- See Note 1	4	-	-	-	8
• FATIGUE (S/N), 3 STRESS LEVELS, 4 SPECIMEN/LEVEL, K_t = 3.0 & 5.0, R = 0.1	Notched Flat		24	24	24	24	24	24 See Note 7
• CRACK PROPAGATION — DIRECTION	See Note 6		L	LT	L	LT	L	LT
			Plate	Plate	Plate	Plate	Plate	Plate
Constant Amplitude								
6CPM, R.T. R = 0.3, Salt Water			1	1	1	1	1	1
360CPM, R.T. R = 0.3, Dry Air			1	1	1	1	1	1
60CPM, R.T. = 0.3, Salt Water			1	1	1	1	1	1
Spectrum Loading (See Note 5)								
360CPM, R.T. Dry Air			2		2		2	

NOTES:
1. For Aluminum, K_{ISCC} in Short Transverse Direction Only
2. For 7050 Aluminum in L Direction Test 3 Specimens at R.T., 3 Specimens at 270°F, 300°F, 350°F after Exposure for 1/2 Hour, 10 Hours, 100 Hours. For All Other Materials, Test 3 Specimens in each of 2 Directions as for K_{IC}
3. For 7050 Aluminum L Direction Test 3 Specimens at R.T. after Exposures at Time and Temperatures in Note 2
4. For 7050 Sheet and 7475 Sheet and Plate, Test 3 Tensile Specimens at R.T. in the LT Direction for 7050 Plate Test, Test 3 Specimens at R.T. in the LT and ST Direction
5. Use on 8 Load Level Spectrum Based on Exceedance Requirements of MIL-A-008866A and Mission Analysis
6. Specimen 16" Dimension in Plate Longitudinal (L) or Long Transverse (LT) Direction
7. K_T = 2.0 & 3.0, R = 0.1

Table XLIV

TENSILE PROPERTIES OF 2024-T851
ALUMINUM ALLOY PLATE, 1½" THICK

Grain Direction	Spec. No.	TYS ksi	TUS ksi	Elong. % in 2"	R.A. %
L ↓	10	67.1	71.6	6.0	17.4
	12	68.0	72.2	7.0	24.3
	AV.	67.5	71.9	6.5	20.8
LT ↓	9	65.1	70.3	5.0	13.3
	11	65.1	70.1	5.0	12.6
	AV.	65.1	70.2	5.0	12.9
Center Thickness Specimens					

Alcoa Lot 217-921

Table XLV

ROOM AND ELEVATED TEMPERATURE TENSILE PROPERTIES OF
7050-T76 ALUMINUM ALLOY SHEET, 0.06" THICK

Exposure Temp. °F	Exposure Time Hours	Grain Direct.	Room Temp. Tests: Spec. No.	TYS ksi	TUS ksi	Elong. % in 2"	Tested at Elevated Temperature After Exposure for Indicated Time: Test Temp. °F	Spec. No.	TYS ksi	TUS ksi	Elong. % in 2"
None	None	L	13	80.6	85.3	10.0					
			15	81.1	85.3	10.0					
			121	81.6	86.4	10.0					
			AV.	81.1	85.7	10.0					
		LT	93	77.3	85.4	9.5					
			94	77.3	85.4	9.5					
			95	77.4	85.3	10.0					
			AV.	77.3	85.4	9.7					
270	0.5	L	20	78.0	83.6	10.0	270	18	66.7	67.7	11.5
			40	77.4	83.0	9.5		19	65.7	66.3	12.0
			60	76.9	82.5	9.5		23	64.9	67.9	12.0
			AV.	77.4	83.1	9.7		AV.	65.8	67.3	11.8
	10		25	77.0	83.0	10.0		30	65.1	65.8	13.5
			42	76.8	82.6	9.5		41	64.4	65.1	13.0
			51	76.2	82.0	9.5		111	64.7	65.0	13.0
			AV.	76.7	82.5	9.7		AV.	64.7	65.3	13.2
	100		26	74.0	80.5	9.5		31	61.9	62.1	14.0
			43	74.0	80.8	10.0		61	62.1	62.5	13.5
			52	73.9	80.7	10.0		112	62.2	62.5	14.0
			AV.	74.0	80.7	9.8		AV.	62.1	62.4	13.8
300	0.5	L	32	77.1	83.9	10.0	300	14	63.0	63.6	14.0
			44	77.4	83.3	10.0		16	60.3	63.1	14.0
			50	77.1	83.3	9.5		21	60.9	64.3	14.0
			AV.	77.2	83.5	9.8		AV.	61.4	63.8	14.0
	10		45	75.6	81.6	10.0		33	60.3	60.8	14.0
			54	75.1	81.6	10.0		53	60.6	61.1	14.0
			62	75.7	81.6	10.0		113	60.1	60.8	14.0
			AV.	75.5	81.6	10.0		AV.	60.3	61.0	14.0
	100		47	63.2	72.9	10.5		27	51.2	51.4	16.0
			55	62.8	72.4	10.5		46	50.9	51.0	15.5
			AV.	63.0	72.6	10.5		114	49.8	50.7	17.0
								AV.	50.6	51.0	16.2
350	0.5	L	28	74.0	80.5	10.5	350	17	51.9	53.2	15.0
			35	74.1	80.9	10.5		22	52.7	54.4	15.0
			56	74.1	80.9	10.0		24	53.1	54.8	15.0
			AV.	74.1	80.8	10.3		AV.	52.6	54.1	15.0
	10		37	60.8	71.1	10.0		36	44.2	45.2	17.0
			38	60.8	71.2	10.5		48	43.3	45.0	17.5
			57	60.0	70.4	10.5		115	43.4	44.3	17.5
			AV.	60.5	70.9	10.3		AV.	43.6	44.8	17.3
	100		39	42.8	57.5	10.0		29	28.9	32.8	22.0
			49	42.1	56.4	10.0		58	28.4	32.3	21.5
			59	41.8	56.1	10.0		116	28.0	32.4	22.0
			AV.	42.2	56.7	10.0		AV.	28.4	32.5	21.8

*All tests from 0.06 x 48 x 48 inches sheet from Alcoa lot 109-216.

Table XLVI

ROOM AND ELEVATED TEMPERATURE TENSILE PROPERTIES OF
7050-T73651 ALUMINUM ALLOY PLATE, 3" THICK

Exposure Temp.	Exposure Time Hour	Grain Direct.	Room Temp. Test Spec. No.	TYS KSI	TUS KSI	Elong. % in 4D	R.A. %	Tested at Elevated Temperature After Exposure for Indicated Time: Test Temp. °F	Spec. No.	TYS KSI	TUS KSI	Elong. % in 4D	R.A. %
None	None	L	19B	70.8	78.5	8.5	19.9						
			22A	70.7	78.7	10.0	18.8						
			25A	69.2	76.2	10.5	20.0						
			AV.	70.2	77.8	9.7	19.6						
		LT	42A	69.1	77.2	8.0	19.6						
			43A	68.8	76.9	8.5	22.5						
			43B	70.1	78.8	8.0	16.4						
			AV.	69.3	77.6	8.2	19.5						
		ST	77	65.3	72.5	1.3	5.4						
			78	65.0	73.9	2.4	7.1						
			79	65.0	73.4	2.2	6.7						
			AV.	65.1	73.3	2.0	6.4						
270	0.5	L	26B	71.1	78.9	8.0	20.2	270	25B	62.1	63.6	12.5	32.2
			31A	69.4	76.4	9.5	26.1		35A	61.3	61.5	12.5	37.5
			36B	70.6	77.6	9.5	20.1		38B	62.0	63.3	11.5	32.7
			AV.	70.4	77.6	9.0	22.1		AV.	61.8	62.8	12.2	34.1
	10		15A	69.4	76.2	9.5	27.0		26A	61.0	61.8	12.0	35.4
			27A	69.6	76.1	9.0	28.4		30B	62.4	62.9	12.0	32.0
			28A	69.5	76.0	10.0	28.6		31B	62.3	64.6	10.0	29.0
			AV.	69.5	76.1	9.5	28.1		AV.	61.9	63.1	11.3	32.1
	100		20A	67.4	74.8	10.0	28.8		15B	61.9	62.9	12.5	34.2
			20B	69.0	77.1	9.5	21.7		18A	60.3	60.3	13.0	38.5
			23A	67.1	74.0	10.0	28.6		37A	60.0	60.0	12.0	38.4
			AV.	67.8	75.3	9.8	26.4		AV.	60.7	61.1	12.5	37.0
300	0.5	L	16B	70.3	78.1	9.0	21.9	300	14B	59.1	59.6	12.0	34.5
			24B	70.5	78.7	9.0	18.9		17B	60.3	60.6	12.0	38.0
			29B	70.9	78.5	10.0	19.6		39B	58.6	59.4	13.0	37.7
			AV.	70.8	78.4	9.3	20.1		AV.	59.3	59.9	12.3	36.7
	10		13B	69.8	78.1	9.0	20.5		17A	57.7	58.0	13.0	40.9
			34A	68.0	75.5	10.5	30.6		22B	58.2	58.4	13.0	41.5
			41A	68.2	74.9	11.0	30.3		24A	57.6	58.0	12.5	41.5
			AV.	68.7	76.2	10.2	27.1		AV.	57.8	58.1	12.8	41.3
	100		27B	62.1	72.1	10.5	20.4		28B	52.4	52.7	14.0	40.1
			32A	60.1	70.0	12.0	35.8		35B	52.4	52.7	15.0	40.7
			40A	59.8	69.7	10.5	33.5		40B	51.5	52.7	14.0	41.2
			AV.	60.7	70.6	11.0	29.9		AV.	52.1	52.7	14.3	40.7
350	0.5	L	32B	69.0	77.1	8.5	18.7	350	33A	53.3	53.4	14.0	41.7
			37B	68.5	77.1	9.0	19.9		33B	54.0	54.1	14.0	40.3
			38A	67.0	74.5	10.5	29.1		34B	53.0	53.2	14.0	41.0
			AV.	68.2	76.2	9.3	22.6		AV.	53.4	53.6	14.0	40.9
	10		13A	57.3	68.2	12.0	32.2		21A	45.1	45.1	16.0	51.0
			14A	57.3	68.0	11.0	32.2		30A	45.6	45.6	16.0	48.4
			29A	57.0	67.8	11.0	30.7		39A	45.0	45.6	16.0	50.9
			AV.	57.2	68.0	11.3	31.7		AV.	45.2	45.4	16.0	50.1
	100		19A	41.8	55.9	12.0	37.0		16A	34.3	34.3	19.5	60.0
			21B	42.3	56.1	11.5	31.1		36A	33.6	33.6	23.0	65.7
			23B	42.5	56.6	11.5	28.6		41B	34.4	34.4	20.0	61.8
			AV.	42.2	56.2	11.7	32.2		AV.	34.1	34.1	20.8	62.5

All longitudinal & long transverse specimens from ¼ thickness level.

Alcoa Lot 729-091

Table XLVII

TENSILE PROPERTIES OF 3-INCH THICK 7050-T73651 PLATE-VENDOR TESTS*

Direction	Tensile Ultimate Strength KSI	Tensile Yield Strength KSI	Elongation % in 4 Times Diameter
Long Transverse	75.2	65.4	10.0
	76.9	67.7	10.5
	74.7	65.2	8.0
	76.4	67.6	8.5
	77.3	69.2	9.5
	75.3	66.5	8.0
Longitudinal	74.1	66.0	13.0
	74.7	67.0	11.0
	74.3	65.9	12.0
	75.1	67.7	10.0
	77.8	70.8	10.0
	77.8	69.9	12.0
Short Transverse	72.3	64.1	4.8
	73.5	63.1	3.6
	73.3	62.6	5.6
	74.1	63.6	3.6
	73.9	65.2	4.1
	74.5	65.2	4.8

*Tests certified by Alcoa from their Lot No. 729-091 on 3" thick x 60" wide plates. Half of those in each direction were from different ends of the parent plate.

Table XLVIII

TENSILE PROPERTIES OF 7475 ALUMINUM ALLOY
(ROOM TEMPERATURE TESTS)

7475-T7351 Plate	Grain Direction	Spec. No.	TUS KSI	TYS KSI	Elong. % in 2"	R.A. %
1.5" Thick	L	75-27	71.1	61.1	14.5	50.4
(Alcoa Lot	L	75-28	71.2	61.4	14.5	51.5
#S-416232	L	75-29	72.1	62.5	14.5	50.2
from master lot #S395607)	Average		71.5	61.7	14.5	50.7
	LT	75-16	70.3	60.4	14.0	44.4
	LT	75-17	70.4	60.0	14.0	44.1
	LT	75-18	70.1	59.8	14.0	44.9
	Average		70.3	60.1	14.0	44.5
Alcoa Expected	L		65	52		
Minimums*	LT		65	52	6	
7475-T761						
.125" Thick	L	75-13	73.8	66.6	15.0	
Sheet	L	75-14	73.8	66.8	15.0	
(Alcoa lot	L	75-29	74.5	67.4	12.5**	
#102-145	L	75-30	74.3	66.5	12.5**	
from master lot #681-036)	Average		74.1	66.8	13.8	
	LT	75-15	74.5	66.3	13.0	
	LT	75-16	74.6	65.2	12.0	
	LT	75-16A	75.0	66.1	12.0	
	Average		74.7	65.9	12.3	
Alcoa Expected	L		70	61		
Minimums*	LT		71	60	9	

Notes: Test specimen configurations: Plate - .505" dia. sheet - flat polished to .112" or .113" thick. Plate specimens were from center thickness.

* Alcoa Green Letter Report No. 216 (Rev. 10/71) Ref 1

** The -29 and -30 specimens were from one end of a 48" x 144" sheet while -13 and -14 specimens were from the other end.

Table XLIX

TENSILE PROPERTIES OF
TI-8MO-8V-2FE-3AL TITANIUM ALLOY SHEET, 0.12" THICK
LONGITUDINAL DIRECTION

CONDITION STA

Specimen No.	TYS ksi	TUS ksi	Elong. % in 2"
As Rec'd			
25	179.8	193.7	6.5
26	179.4	192.9	7.0
27	179.3	192.9	6.0
AV.	179.5	193.2	6.5
Reaged 6 Hours at 1050F			
28	173.4	184.2	9.5
29	173.9	185.1	7.5
30	168.9	183.1	8.0
AV.	172.1	184.1	8.3

Strain Rate = .005 inch/inch/min.

Table L

TENSILE PROPERTIES OF
TI-8MO-8V-2FE-3AL TITANIUM ALLOY PLATE, 1" THICK

Grain Direction	Specimen No.	TYS ksi	TUS ksi	Elong. % in 4D	R.A. %
Longitudinal	8-21	169.1	172.5	2.5	8.7
	-22	168.7	173.2	2.5	7.0
	-23	169.5	172.5	2.5	7.9
	-41	173.1	176.5	3.27	8.4
	-42	173.6	176.6	2.86	7.7
	-43	166.6	171.1	3.16	7.1
	-44	167.6	172.5	3.54	8.0
	AV.	169.7	173.6	2.9	7.8
Long Transverse	8-13	175.7	182.1	2.0	6.4
	-14	179.5	184.0	2.0	5.5
	-15	175.8	180.3	2.0	5.3
	AV.	177.0	182.1	2.0	5.7

TMCA Heat V-4734
Strain Rate .005 inch/inch/min.
Reaged for 6 hours at 1100F at General Dynamics. "Condition STA"

Table LI

COMPRESSION PROPERTIES OF 7050-T76
SHEET, .06″ THICK

Grain Direction	Test Temp. °F	Time at Temp., Hr.	Spec. No.	CYS KSI	% R.T. CYS
LT	RT	-	50-268	81.8	
		-	50-265	81.7	
		-	50-267	79.3	
			AVG.	80.9	—
L		-	50-259	76.2	
		-	50-260	76.2	
		-	50-263	75.9	
			AVG.	76.1	—
L	270	0.5	50-240	67.3	
			50-241	68.2	
			50-242	67.7	
			AVG.	67.7	89.0
		10	50-201	67.6	
			50-202	68.4	
			50-203	69.1	
			AVG.	68.4	89.9
		100	50-208	67.0	
			50-209	68.7	
			50-210	68.7	
			AVG.	68.1	89.5
L	300	0.5	50-246	66.1	
			50-247	67.5	
			50-249	67.6	
			AVG.	67.1	88.2
		10	50-213	67.2	
			50-214	65.4	
			50-215	65.0	
			AVG.	65.9	86.6
		100	50-219	54.2	
			50-220	55.8	
			50-222	55.9	
			AVG.	55.3	72.7
L	350	0.5	50-252	61.5	
			50-253	61.8	
			50-254	63.6	
			AVG.	62.3	81.9
		10	50-225	48.2	
			50-226	48.8	
			50-227	49.1	
			AVG.	48.7	64.0
		100	50-231	35.1	
			50-232	34.3	
			50-233	35.0	
			AVG.	34.8	45.7

Alcoa Lot No. 109-216

Table LII

COMPRESSION PROPERTIES OF 7050-T73651
PLATE, 3" THICK*

Test Temp. °F	Grain Dir.	Controls Spec. No.	Controls CYS KSI	1/2 hour Spec. No.	1/2 hour CYS KSI	10 hour Spec. No.	10 hour CYS KSI	100 hour Spec. No.	100 hour CYS KSI
RT	LT	68A	70.2						
	LT	68B	71.3						
	LT	69A	72.2						
		AVG	71.2						
	L	70A	67.9						
	L	70B	67.5						
	L	71A	67.7						
		AVG	67.7						
270°F	L			65A	59.5	64	60.1	63B	58.3
	L			72A	59.7	67B	59.6	66B	56.9
	L			74B	59.5	71B	59.6	76B	58.2
				AVG	59.6		59.8		57.8
				% of RT	88.0		88.3		85.4
300°F	L			61A	57.9	67A	50.4	61B	49.3
	L			62A	58.1	75A	51.4	64B	49.5
	L			73A	57.8	80A	51.1	73B	49.9
				AVG	57.9		51.0		49.6
				% of RT	85.5		75.3		73.3
350°F	L			62B	51.8	66A	43.8	63A	32.5
	L			65B	51.9	72B	44.2	74A	32.7
	L			76A	52.0	75B	44.5	80B	33.8
				AVG	51.9		44.2		33.0
				% of RT	76.7		65.3		48.7

*Testing per ASTM E9 Specimens 1.0" dia. X 3.0" long from plate 1/4 thickness level. Specimens were from a 3 x 60 (wide) x 50 (long) inches 7050-T73651 plate obtained from the Grumman Aerospace Corporation. This plate was originally identified by Alcoa as X7050-T7E64 and was from Alcoa lot 729-091.

Table LIII

FRACTURE TOUGHNESS PROPERTIES OF 1½ INCHES THICK 2024-T851 ALUMINUM ALLOY PLATE

Specimen Direction	Spec. No.	Thickness Inch	K_{Ic} ksi-$\sqrt{in.}$
L-T	13	1.0	24.6
	14	1.0	25.2
↓	AV.		24.9
L-S	15	0.6	26.0
	16	0.6	26.2
↓	AV.		26.1

Alcoa lot 217-921

CT SPECIMENS

SPECIMEN NO.	P(Q) LB	B INCH	W INCH	A INCH	K(IC) PSI $\sqrt{\text{INCH}}$
2024-13 RW	3550.0	1.0000	1.9865	1.0037	24573
2024-14 RW	3640.0	1.0005	2.0048	1.0176	25245
2024-15 RT	1650.0	0.6015	1.2003	0.6300	25956
2024-16 RT	1700.0	0.6020	1.2002	0.6226	26211

Table LIV

FRACTURE TOUGHNESS PROPERTIES OF 3.0 INCHES THICK 7050-T73651 ALUMINUM ALLOY PLATE

Specimen No. *	Specimen Thickness (in.)	Loading-Crack Propagation Direction	K_{Ic}** (ksi-$\sqrt{in.}$)
7050-52A	1.0	L-T	28.2
7050-52B	1.0	↓	26.1
7050-60A	1.0	↓	27.3
		AVG.	27.2
7050-53	1.0	S-L	22.6
7050-54	1.0	↓	23.5
7050-55	1.0	↓	22.7
		AVG.	22.9

* Alcoa lot No. 729-091 on 3.0" thick x 60" wide plate.
** Compact tension specimens tested per ASTM E399-70T.

CT SPECIMENS

SPECIMEN NO.	P(Q) LB	B INCH	W INCH	A INCH	K(IC) PSI $\sqrt{\text{INCH}}$
7050-52A RW RT	4030.0	1.0000	1.9921	1.0138	28167
7050-52B RW RT	3820.0	1.0002	2.0101	1.0105	26080
7050-60A RW RT	3950.0	0.9998	2.0093	1.0184	27322
7050-53 TR RT	3140.0	1.0004	1.9918	1.0335	22624
7050-54 TR RT	3300.0	1.0002	1.9954	1.0290	23526
7050-55 TR RT	3210.0	0.9989	1.9998	1.0252	22675

Table LV

FRACTURE TOUGHNESS PROPERTIES 1.5 INCHES THICK
7475-T7351 ALUMINUM ALLOY PLATE

Specimen No.	Specimen Thickness (in.)	Loading-Crack Propagation Direction	K_Q [1] (ksi-$\sqrt{\text{in.}}$)
75-13	1.5	L-T	63.0
75-14	1.5	↓	63.7
75-15	1.5	↓	65.3
AVG.		↓	64.0

NOTE 1. These three specimens and their tests met all the validity requirements of ASTM E399-T71 except specimen thickness. This specimen thickness requirement of $t \geq 2.5\ (K_{IC}/YS)^2$ would require thickness to be 2.6 to 2.8 inches using yield strength from Table III. The specimen used would have been valid for the expected K_{IC} of 47 KSI - $\sqrt{\text{in.}}$

CT SPECIMENS - L-T DIRECTION

SPECIMEN NO.	P(Q) LB	B INCH	W INCH	A INCH	K(IC) PSI $\sqrt{\text{INCH}}$
75-13	14960.	1.4510	3.0017	1.5950	62989
75-14	15200.	1.4520	3.0020	1.5920	63735
75-15	15520.	1.4520	3.0010	1.5945	65301

Table LVI

FRACTURE TOUGHNESS OF 1.0 INCH THICK
TI-8MO-8V-2FE-3AL TITANIUM ALLOY PLATE

Specimen No.	Specimen Thickness Inch	Loading-Crack Propagation Direction	K_{Ic} KSI-$\sqrt{in.}$
8-26	1.0	L-T	53.1
8-29			53.9
8-30			55.0
AV.			54.0
8-31	1.0	T-L	53.2
8-32			55.0
8-33			53.4
AV.			53.9

CT SPECIMENS

SPECIMEN NO.	P(Q) LB	B INCH	W INCH	A INCH	K(IC) PSI $\sqrt{INCH}$
8-26 LT	7830.0	1.0020	1.9900	0.9940	53118
8-29 LT	8000.0	1.0050	1.9950	0.9950	53921
8-30 LT	7985.0	0.9980	1.9890	1.0010	55017
8-31 TL	7580.0	0.9960	1.9930	1.0140	53158
8-32 TL	7945.0	0.9980	1.9950	1.0080	54989
8-33 TL	7870.0	0.9910	1.9910	0.9870	53369

Table LVII

STRESS CORROSION PROPERTIES OF
7050-T73651 ALUMINUM ALLOY PLATE, 3" THICK

Specimen No.	K_{Ii} ksi-$\sqrt{\text{in.}}$	Time to Failure Hours	K_{Ii}/K_{Ic}	Residual K_Q ksi-$\sqrt{\text{in.}}$
50-56	19.2	1073 NF	.84	22.6
50-57	20.1	1227 NF	.88	22.4
50-58*	22.3	1033 NF	.97	24.4
50-59‡	23.8	FOL	1.00	-
$\therefore K_{Iscc} \approx K_{Ic}$				

Testing direction, S-L
Stagnant 3.5% NaCl replaced weekly
*Flowing corrodent, quart/hour
‡Progressively step loaded as shown in Figure 94
NR-No Failure
FOL-Failed on Loading

CT SPECIMENS

SPECIMEN NO.	P(Q) LB	B INCH	W INCH	A INCH	K(IC) PSI $\sqrt{\text{INCH}}$
7050-56 3.5 NACL	2600.0	1.0010	2.0000	1.0538	19164
7050-56 STATIC	3060.0	1.0010	2.0000	1.0538	22554
7050-57 3.5 NACL	2880.0	1.0005	2.0030	1.0202	20090
7050-57 STATIC	3000.0	1.0005	2.0030	1.0632	22385
7050-58 3.5 NACL FLOWING	2880.0	1.0018	2.0050	1.0871	22268
7050-58 STATIC	3150.0	1.0018	2.0050	1.0871	24356
7050-59 3.5 NACL STAGNANT	3300.0	1.0003	2.0004	1.0403	23815

Table LVIII

STRESS CORROSION PROPERTIES
OF Ti-8Mo-8V-2Fe-3Al STA, 1" THICK PLATE

Test Direction	Spec. No.	K_{Ii} ksi-$\sqrt{\text{in.}}$	Time to Failure, Hr.	K_{Ii}/K_{Ic}
L-T	8-27	27.0	0.08	0.50
	8-25	23.3*	0.07	0.43
	8-28	23.7*	0.7	0.44
	Av. K_{Iscc} =23.5			0.43
T-L	8-34	42.6	0.05	0.79
	8-37	21.7*	0.06	0.40
	8-35	23.9*	0.08	0.44
	8-26	24.3*	0.04	0.45
	Av. K_{Iscc} =23.3			

Precracked compact tension specimens tested in 3.5% NaCl.
*Progressively step loaded to failure (see Figure 95)

CT SPECIMENS

SPECIMEN NO.	P(Q) LB	B INCH	W INCH	A INCH	K(II) PSI $\sqrt{\text{INCH}}$
8-27 LT 3.5 NACL	4000.0	1.0050	1.9880	0.9920	27028
8-34 TL 3.5 NACL	6400.0	1.0000	1.9940	0.9830	42631
8-37 TL 3.5 NACL	3200.0	0.9980	1.9890	0.9910	21720
8-25 LT 3.5 NACL	3400.0	0.9980	1.9810	0.9920	23298
8-35 TL 3.5 NACL	3500.0	0.9990	1.9880	0.9960	23934
8-28 LT 3.5 NACL	3500.0	1.0020	1.9870	0.9900	23673
8-36 TL 3.5 NACL	3500.0	0.9830	1.9870	0.9960	24349

Table LIX

NOTCHED AXIAL FATIGUE PROPERTIES OF
7050-T76 SHEET, 0.06" THICK
LONGITUDINAL GRAIN, R=0.1, K_T=3 OR 5

Specimen No.	Maximum Fatigue Stress, ksi	Cycles to Failure, $x10^3$	Remarks
K_t=3			
50-100	40	2.85	
-101	40	2.70	
-99	20	37	
-102	↓	44	
-104	↓	36	
-105	↓	32	
-106	15	115	
-107	15	117	
-103	14	1348	
-109	13	1723	
-110	13	8126	
-108	10	10189	NF (F_{ntu}=90.8 ksi)‡
K_t=5			
50-3	40	1.8	
-4	40	2.1	
-1	20	20	
-7	20	23	
-5	15	56	
-9	15	50	
-10	13	116	
-8	10	10089	NF (F_{ntu}=87.2 ksi)‡
-11	↓	614	
-12	↓	189	
-2	8	10037	NF (F_{ntu}=87.6 ksi)‡
-6	8	15080	NF (F_{ntu}=87.7 ksi)‡

Alcoa Lot 109-216

‡ F_{ntu}= Notched tensile strength after each specimen had been removed from fatigue testing.

Table LX

NOTCHED AXIAL FATIGUE PROPERTIES OF
7050-T73651 ALUMINUM ALLOY PLATE,
3" THICK, LONGITUDINAL GRAIN, ¼ THICKNESS LOCATION

Specimen No.	Maximum Fatigue Stress, ksi	Cycles to Failure, X 1000	Remarks
K_t= 3			
50-1B	40	3.3	
-2B	40	3.3	
-3B	40	2.6	
-5B	20	82	
-6B	20	96	
-1A	20	84	
-2A	20	105	
-4B	18.5	906	
-5A	18.5	12330	NF (F_{ntu}=79.8 ksi)
-4A	17	4323	NF
-6A	17	10386	NF (F_{ntu}=79.1 ksi)
-3A	15	10045	NF (F_{ntu}=79.8 ksi)
K_t= 5			
50-7A	40	2.25	
-8A	40	2.15	
-11A	20	38	
-12A	20	82	
-7B	20	52	
-8B	20	122	
-9B	15	266	
-11B	15	147	
-10B	13	389	
-12B	13	948	
-9A	12	10197	NF (F_{ntu}=75.3 ksi)
-10A	10	10192	NF (F_{ntu}=76.2 ksi)

Table LXI

NOTCHED AXIAL FATIGUE PROPERTIES OF 7475-T761 SHEET*, .125" THICK LONGITUDINAL GRAIN, R=0.1, K_t=3 OR 5

SPECIMEN NO.	MAXIMUM FATIGUE STRESS, KSI	CYCLES TO FAILURES, X 10^3	REMARKS
K_t= 3			
75-1	40	5	
-2	↓	4	
-3		4	
-4	40	4	
-5	20	63	
-6	↓	446	
-7		159	
-8	20	89	
-9	17	2195	Grip Failure
-10	↓	285	
-11		10344	NF (F_{ntu}=80.3 ksi)≠
-12	17	14701	NF (F_{ntu}=80.2 ksi)≠
K_t= 5			
-17	20	51	
-18	↓	33	
-19		86	
-21	15	461	
-22	↓	194	
-23		129	
-25		259	
-26	12	226	
-27	↓	4248	
-28		4287	
-24	10	15505	NF (F_{ntu}=78.3 ksi)≠
-20	10	10120	NF (F_{ntu}=77.8 ksi)≠

*Specimens were from 0.125 X 48 X 144 inches sheet of 7475-T61 from Alcoa Lot 102-145 artificially aged at Convair to the -T761 temper.

≠F_{ntu} = Notched tensile ultimate strength after each specimen had been removed from fatigue testing.

Table LXII

NOTCHED AXIAL FATIGUE PROPERTIES OF
7475-T7351, 1.5" THICK PLATE, LONGITUDINAL
GRAIN, R=0.1, K_t=3 OR 5, ¼ THICKNESS LOCATION

Specimen No.	Max. Fatigue Stress, ksi	Cycles to Failure, X1000	Remarks
K_t=3			
75-7B	40	4	
-8B	↓	4	
-10B	↓	4.7	
-11B	20	60	
-12B	↓	90	
-7A	↓	55	
-8A	↓	76	
-9B	17	102	
-11A	↓	173	
-12A	↓	188	
-9A	15	12635	NF (F_{ntu}=60.5 ksi) ≠
-10A	15	10018	NF * (F_{ntu}=75.9 ksi) ≠
K_t=5			
75-5A	40	3.6	
-1B	↓	3.1	
-4B	↓	3.6	
-1A	15	338	
-2A	↓	3304	
-3A	↓	426	
-4A	↓	2563	
-3B	13	10429	NF * (F_{ntu}=70.1 ksi) ≠
-5B	↓	853	
-6B	↓	829	
-2B	12	10186	NF * (F_{ntu}=70.8 ksi) ≠
-6A	10	10279	NF (F_{ntu}=73.4 ksi) ≠

*Very small (.002" deep) fatigue crack in one radius

≠ These notched tensile ultimate values were obtained after the specimen had been fatigue cycled as noted to the left.

Table LXIII

NOTCHED AXIAL FATIGUE PROPERTIES OF
Ti-8Mo-8V-2Fe-3Al SHEET, 0.12 " THICK
R=0.1, LONGITUDINAL GRAIN, K_t=3 OR 5

Specimen No.	Maximum Fatigue Stress, ksi	Cycles to Failure, X 10^3	Remarks
K_t=3			
8-7*	80	1.8	Rerun
-5*	80	2.94	
-1	50	12	
-2	↓	11	
-4*	↓	10	
-9*	↓	13	
-10*	30	56	
-11*	↓	26	
-12	↓	36	
-5*	25	2516	NF
-6*	25	20816	NF (F_{ntu}=194.5 ksi)
-3	20	10353	NF
-8	15	4294	NF (F_{ntu}=189.5 ksi)
K_t=5			
8-22*	70	2.07	
-16*	50	7	
-18*	↓	7	
-19*	↓	8	
-13*	30	37	
-14*	20	79	
-17*	↓	80	
-20*	↓	85	
-21*	17	126	
-24*	17	26649	NF (F_{ntu}=157.3 ksi)
-15*	15	10008	NF (F_{ntu}=145.6 ksi)
-23*	15	15566	NF (F_{ntu}=145.4 ksi)

* Reaged 6 hours at 1050F. Condition STA

Table LXIV
NOTCHED AXIAL FATIGUE PROPERTIES OF
TI-8MO-8V-2FE-3AL PLATE, 1" THICK
STA CONDITION, LONGITUDINAL GRAIN
R = 0.1, K_T = 3 OR 2

Specimen No.	Maximum Fatigue Stress, KSI	Cycles to Failure, $X10^3$	Remarks
K_t=3			
8-10B	80	2.62	f=6 Hz
-11B	80	2.25	"
-8B	50	19.48	"
-9A	50	15.09	"
-11A	50	13.60	"
- 9B	35	64	
-12A	35	55	
- 7A	33	112	
-10A	33	63	
- 7B	30	7749	
- 8A	30	10348	NF (F_{ntu} = 154.9 KSI)
-12B	30	99	
K_t=2			
8-5A	100	4.14	f=6 Hz
-5B	100	3.41	"
-3B	80	9	
-6A	80	8	
-1B	60	333	f=6 Hz
-3A	60	220	"
-4A	60	60	
-1A	57	-	Failed in hole
-4B	57	360	
-6B	57	486	
-2B	55	10704	NF (F_{ntu} = 186.0 KSI)
-2A	50	1050	*NF (F_{ntu} = 147.7 KSI) f = 6 Hz

* Fatigue crack at notch invalidates F_{ntu}.

Table LXV

AV. NOTCH TENSILE STRENGTH OF ALLOYS

Alloy	Form	$K_t = 3$ NTUS ksi	$K_t = 3$ $\frac{NTUS}{TUS}$	$K_t = 5$ NTUS ksi	$K_t = 5$ $\frac{NTUS}{TUS}$
7050-T76	.060" Sheet	90.8	1.06	87.5	1.02
7050-T73651	3" Plate	79.6	1.02	75.7	0.97
7475-T761	.125" Sheet	80.2	1.08	78.0	1.05
7475-T7351	1½" Plate	-	-	73	1.02
Ti-8-8-2-3 STA	.125" Sheet	192.0	1.04	149.6	0.81
Ti-8-8-2-3 STA	1" Plate	155	0.89	186*	1.07

Values obtained from unfailed fatigue specimens tested below endurance limit.

*$K_t = 2$

Table LXVI
SURFACE FLAW SPECIMEN 50-44

SURFACE FLAW SPECIMEN 7050-T73651 50-44
TEMPERATURE RT L-S DIRECTION
ENVIRONMENT DRY AIR 360CPM
YIELD STRENGTH 70200 PSI R = 0.30
B = 0.4910 INCH W = 3.0020 INCHES

P MAX KIPS	A INCH	2C INCH	DN X1000	DELTA K CENTER KSI/ INCH	DELTA K SURFACE KSI/ INCH	DA/DN -MICROINCHES/CYCLE-	DC/DN -MICROINCHES/CYCLE-	D(A/Q) DN -MICROINCHES/CYCLE-	A/B	A/Q	A/2C
0.0	0.0540	0.1750	0.0	0.00	0.00				0.11	0.033	0.309
15.0	0.0550	0.1800	20.0	2.54	1.99	0.050	0.125	0.045	0.11	0.033	0.306
15.0	0.0590	0.1900	60.0	2.62	2.06	0.067	0.083	0.034	0.12	0.036	0.311
15.0	0.0620	0.1970	40.0	2.67	2.12	0.075	0.088	0.037	0.13	0.037	0.315
15.0	0.0680	0.2150	50.0	2.79	2.22	0.120	0.180	0.069	0.14	0.040	0.316
15.0	0.0770	0.2380	90.0	2.95	2.37	0.100	0.128	0.052	0.16	0.045	0.324
15.0	0.0810	0.2470	70.0	3.01	2.44	0.057	0.064	0.027	0.17	0.047	0.328
15.0	0.0840	0.2570	50.0	3.07	2.48	0.060	0.100	0.037	0.17	0.049	0.327
15.0	0.0930	0.2770	70.0	3.20	2.62	0.129	0.143	0.060	0.19	0.053	0.336
15.0	0.1260	0.3520	40.0	3.64	3.08	0.250	0.275	0.114	0.26	0.069	0.358
15.0	0.1300	0.3620	40.0	3.69	3.13	0.100	0.125	0.050	0.26	0.071	0.359
15.0	0.1340	0.3700	40.0	3.74	3.18	0.100	0.100	0.043	0.27	0.072	0.362
15.0	0.1530	0.4100	30.0	3.95	3.41	0.633	0.667	0.279	0.31	0.081	0.373
15.0	0.1620	0.4270	70.0	4.03	3.51	0.129	0.121	0.052	0.33	0.084	0.379
15.0	0.2130	0.5250	40.0	4.50	4.05	0.600	0.550	0.232	0.43	0.105	0.406
15.0	0.2550	0.5970	30.0	4.81	4.45	1.400	1.200	0.507	0.52	0.120	0.427

Table LXVII
SURFACE FLAW SPECIMEN 50-49

SURFACE FLAW SPECIMEN 7050-T73651 50-49
TEMPERATURE RT T-S DIRECTION
ENVIRONMENT DRY AIR 360 CPM
YIELD STRENGTH 69300 PSI R = 0.30
B = 0.5065 INCH W = 3.0020 INCHES

P MAX KIPS	A INCH	2C INCH	DN X1000	DELTA K CENTER KSI/ INCH	DELTA K SURFACE KSI/ INCH	DA/DN -MICROINCHES/CYCLE-	DC/DN -MICROINCHES/CYCLE-	D(A/Q) DN -MICROINCHES/CYCLE-	A/B	A/Q	A/2C
0.0	0.1323	0.2120	0.0	0.00	0.00				0.26	0.054	0.624
15.0	0.1392	0.2230	60.0	3.20	3.58	0.115	0.092	0.048	0.27	0.057	0.624
15.0	0.1410	0.2260	60.0	3.22	3.60	0.030	0.025	0.012	0.28	0.057	0.624
15.0	0.1423	0.2280	40.0	3.24	3.62	0.033	0.025	0.013	0.28	0.058	0.624
15.0	0.1466	0.2350	40.0	3.29	3.67	0.108	0.088	0.044	0.29	0.060	0.624
17.0	0.1560	0.2500	30.0	3.84	4.29	0.313	0.250	0.128	0.31	0.063	0.624
17.0	0.1572	0.2520	30.0	3.86	4.31	0.040	0.033	0.016	0.31	0.064	0.624
17.0	0.1610	0.2580	40.0	3.90	4.36	0.095	0.075	0.039	0.32	0.065	0.624

Table LXVIII
SURFACE FLAW SPECIMEN 50-45

SURFACE FLAW SPECIMEN 7050-T73651 50-45
TEMPERATURE RT L-S DIRECTION
ENVIRONMENT 3.5% NACL 60CPM
YIELD STRENGTH 70200 PSI R = 0.30
B = 0.4198 INCH W = 3.0060 INCHES

P MAX KIPS	A INCH	2C INCH	DN X1000	DELTA K CENTER KSI/ INCH	DELTA K SURFACE KSI/ INCH	DA/DN -MICROINCHES/CYCLE-	DC/DN -MICROINCHES/CYCLE-	D(A/Q) / DN -MICROINCHES/CYCLE-	A/B	A/Q	A/2C
0.0	0.1300	0.2920	0.0	0.00	0.00				0.31	0.059	0.445
12.0	0.1380	0.3100	58.9	3.25	3.06	0.136	0.153	0.063	0.33	0.063	0.445
12.0	0.1460	0.3270	31.0	3.34	3.15	0.258	0.274	0.111	0.35	0.066	0.446
12.0	0.1620	0.3630	66.0	3.52	3.32	0.242	0.273	0.110	0.39	0.073	0.446
12.0	0.1680	0.3780	10.0	3.59	3.38	0.600	0.750	0.300	0.40	0.076	0.444
12.0	0.1770	0.3970	70.0	3.68	3.47	0.129	0.136	0.055	0.42	0.080	0.446
12.0	0.2170	0.4880	75.0	4.08	3.84	0.240	0.267	0.108	0.52	0.099	0.445
12.0	0.2220	0.4980	25.0	4.12	3.89	0.200	0.200	0.082	0.53	0.101	0.446
12.0	0.2780	0.6250	50.0	4.61	4.35	1.120	1.270	0.513	0.66	0.126	0.445

Table LXIX

SURFACE FLAW SPECIMEN 50-50

SURFACE FLAW SPECIMEN 7050-T73651 50-50
TEMPERATURE RT T-S DIRECTION
ENVIRONMENT 3.5% NACL 60CPM
YIELD STRENGTH 69300 PSI R = 0.30
B = 0.4960 INCH W = 3.0050 INCHES

P MAX KIPS	A INCH	2C INCH	DN X1000	DELTA K CENTER KSI/ INCH	DELTA K SURFACE KSI/ INCH	DA/DN -MICROINCHES/CYCLE-	DC/DN -MICROINCHES/CYCLE-	D(A/Q)/DN -MICROINCHES/CYCLE-	A/B	A/Q	A/2C
0.0	0.1230	0.2470	0.0	0.00	0.00				0.25	0.050	0.498
15.0	0.1300	0.2610	50.0	3.16	3.16	0.140	0.140	0.059	0.26	0.053	0.498
15.0	0.1380	0.2760	26.0	3.25	3.25	0.308	0.288	0.117	0.28	0.056	0.500
15.0	0.1460	0.2970	50.0	3.37	3.34	0.160	0.210	0.085	0.29	0.060	0.492
15.0	0.1650	0.3570	100.0	3.69	3.55	0.190	0.300	0.120	0.33	0.072	0.462
15.0	0.2110	0.4730	50.0	4.25	4.01	0.500	0.580	0.234	0.43	0.096	0.446
15.0	0.2280	0.5120	22.0	4.42	4.17	0.773	0.886	0.358	0.46	0.103	0.445
15.0	0.2820	0.6400	10.0	4.94	4.64	1.300	1.750	0.697	0.57	0.129	0.441
15.0	0.2960	0.6680	10.0	5.05	4.75	1.400	1.400	0.572	0.60	0.135	0.443
15.0	0.3120	0.7050	11.0	5.18	4.88	1.455	1.682	0.678	0.63	0.142	0.443
15.0	0.3810	0.8650	8.0	5.74	5.39	5.625	6.563	2.643	0.77	0.175	0.440
15.0	0.4430	1.0140	1.0	6.21	5.81	3.000	4.500	1.773	0.89	0.205	0.437

CENTER CRACK TENSION

P_{MAX} KIPS	dN CYCLES	2C FRONT	2C REAR INCHES	2C AVG.	da/dN x 10^{-6}	ΔK KSI-$\sqrt{IN}$
15	2000	1.043	.125	.584	-	-
11.25	6000	1.097	.620	.859	-	-
15	1000	1.252	.770	1.011	76	9.6
11.25	1700	1.300	.840	1.070	-	-
15	200	1.320	.880	1.100	75	10.1
↓	300	1.335	.905	1.120	33.3	10.2
	500	1.335	1.000	1.168	48	10.5
	500	1.355	1.100	1.228	60	10.9
	500	1.365	1.190	1.278	50	11.3
	500	1.395	1.310	1.353	75	11.8
	600	1.440	-	1.440	72.5	12.4
	400	1.480	-	1.480	50	12.5
	500	1.620	-	1.620	140	13.8
	500	1.742	-	1.742	122	14.9
	500	1.895	-	1.895	153	16.4

Failed statically at 15,400 lbs.

$2C_{AV}$ = 2.298",

$2C_{MAX}$ = 2.36"

Table LXX
SURFACE FLAW SPECIMEN 50-51

SURFACE FLAW SPECIMEN 7050-T73651 50-51
TEMPERATURE RT T-S DIRECTION
ENVIRONMENT 3.5% NACL 6 CPM
YIELD STRENGTH 60100 PSI R = 0.30
B = 0.4980 INCH W = 3.0030 INCHES

P MAX KIPS	A INCH	2C INCH	DN X1000	DELTA K CENTER KSI/ INCH	DELTA K SURFACE KSI/ INCH	DA/DN -MICROINCHES/CYCLE-	DC/DN -MICROINCHES/CYCLE-	D(A/Q)/DN -MICROINCHES/CYCLE-	A/B	A/Q	A/2C
0.0	0.1015	0.2030	0.0	0.00	0.00				0.20	0.041	0.500
15.0	0.1040	0.2080	34.0	2.81	2.81	0.074	0.074	0.033	0.21	0.042	0.500
18.0	0.1085	0.2170	15.0	3.45	3.45	0.300	0.300	0.125	0.22	0.044	0.500
18.0	0.1150	0.2300	60.0	3.55	3.55	0.108	0.108	0.044	0.23	0.047	0.500
20.0	0.1240	0.2480	27.3	4.10	4.10	0.330	0.330	0.136	0.25	0.050	0.500
22.0	0.3060	0.6120	5.7	7.09	7.09	14.727	14.727	6.014	0.61	0.125	0.500
20.0	0.3170	0.6340	2.0	6.56	6.56	5.500	5.500	2.183	0.64	0.129	0.500
20.0	0.3305	0.6610	3.0	6.70	6.70	4.485	4.485	1.826	0.66	0.135	0.500
18.0	0.3370	0.6740	3.2	6.08	6.08	2.055	2.055	0.801	0.68	0.137	0.500
18.0	0.3490	0.6980	5.7	6.19	6.19	2.121	2.121	0.862	0.70	0.142	0.500
20.0	0.4650	0.9300	0.8	7.94	7.94	7.975	7.975	3.432	0.93	0.189	0.500
20.0	0.4880	0.9760	0.8	8.14	8.14	28.221	28.221	11.486	0.98	0.199	0.500

CENTER CRACK TENSION

P_{MAX} KIPS	dN CYCLES	2C FRONT	2C REAR	2C AVG.	da/dN $\times 10^{-6}$	ΔK KSI-$\sqrt{IN}$
20	239	1.002	.252	.627	-	-
20	200	1.010	.311	.661	90	9.8
20	200	1.010	.380	.695	90	10.1
22	106	1.018	.418	.718	110	11.3
22	288	1.041	.523	.782	110	11.9
24	207	1.062	.641	.852	170	13.7
24	205	1.103	.750	.927	180	14.4
24	207	1.123	.851	.987	140	15.0
26	206	1.163	.977	1.070	200	17.1
26	208	1.222	1.146	1.184	270	18.4
26	129	1.285	1.278	1.282	380	19.5
26	200	1.526	1.711	1.619	840	23.8
26	11	1.600	1.755	1.678	2680	24.7

Table LXXI
SURFACE FLAW SPECIMEN 75-21

SURFACE FLAW SPECIMEN 7475-T7351 75-21
TEMPERATURE RT   T-S DIRECTION
ENVIRONMENT DRY AIR   360 CPM
YIELD STRENGTH   60100 PSI   R =   0.30
B = 0.4630 INCH   W =   3.0020 INCHES

P MAX KIPS	A INCH	2C INCH	DN X1000	DELTA K CENTER KSI/ INCH	DELTA K SURFACE KSI/ INCH	DA/DN -MICROINCHES/CYCLE-	DC/DN -MICROINCHES/CYCLE-	D(A/Q) DN -MICROINCHES/CYCLE-	A/B	A/Q	A/2C
0.0	0.1465	0.3330	0.0	0.00	0.00				0.32	0.067	0.440
15.0	0.1474	0.3350	20.0	3.83	3.60	0.045	0.050	0.031	0.32	0.068	0.440
15.0	0.1483	0.3370	20.0	3.84	3.61	0.045	0.050	0.020	0.32	0.068	0.440
15.0	0.1496	0.3400	20.0	3.86	3.62	0.065	0.075	0.030	0.32	0.069	0.440
15.0	0.1509	0.3430	20.0	3.88	3.64	0.065	0.075	0.030	0.33	0.069	0.440
15.0	0.1606	0.3650	50.0	4.00	3.75	0.194	0.220	0.089	0.35	0.074	0.440
15.0	0.1663	0.3780	30.0	4.07	3.82	0.190	0.217	0.088	0.36	0.076	0.440
15.0	0.1751	0.3980	40.0	4.18	3.92	0.220	0.250	0.101	0.38	0.080	0.440
15.0	0.1778	0.4040	16.9	4.21	3.95	0.160	0.178	0.072	0.38	0.082	0.440
15.0	0.1866	0.4240	23.1	4.31	4.05	0.381	0.433	0.175	0.40	0.086	0.440
15.0	0.1900	0.4320	10.0	4.35	4.08	0.340	0.400	0.161	0.41	0.087	0.440
15.0	0.2220	0.5050	20.0	4.71	4.41	0.450	0.550	0.221	0.48	0.102	0.440
15.0	0.2490	0.5660	40.0	4.98	4.67	0.675	0.763	0.308	0.54	0.114	0.440
15.0	0.2720	0.6050	20.0	5.16	4.89	1.150	0.975	0.405	0.59	0.122	0.450
15.0	0.3290	0.7200	20.0	5.63	5.38	1.450	1.600	0.648	0.71	0.146	0.457
15.0	0.3400	0.7750	10.0	5.83	5.46	1.100	2.750	1.064	0.73	0.157	0.439
15.0	0.3987	0.8960	10.0	6.27	5.92	2.870	3.700	1.481	0.86	0.181	0.445
15.0	0.4090	0.9300	3.2	6.39	5.99	3.219	5.312	2.088	0.88	0.188	0.440
15.0	0.4630	1.0660	5.0	6.83	6.37	5.200	7.600	3.005	1.00	0.215	0.434

Table LXXII
SURFACE FLAW SPECIMEN 75-23

SURFACE FLAW SPECIMEN 7475-T7351, #75-23
TEMPERATURE RT
L-S Direction
ENVIRONMENT DRY AIR 360 CPM
YIELD STRENGTH 61700 PSI R = 0.30
B = 0.4200 INCH W = 2.9000 INCHES

P MAX KIPS	A INCH	2C INCH	DN X1000	DELTA K CENTER KSI/ INCH	DELTA K SURFACE KSI/ INCH	DA/DN -MICROINCHES/CYCLE-	DC/DN -MICROINCHES/CYCLE-	D(A/Q) / DN -MICROINCHES/CYCLE-	A/B	A/Q	A/2C
0.0	0.1300	0.2600	0.0	0.00	0.00				0.31	0.053	0.500
15.0	0.1800	0.3600	124.9	4.55	4.55	0.400	0.400	0.164	0.43	0.073	0.500
15.0	0.2200	0.4700	40.0	5.19	5.02	0.500	0.750	0.302	0.52	0.095	0.468
15.0	0.2400	0.5200	20.0	5.46	5.25	1.000	1.250	0.504	0.57	0.106	0.462
15.0	0.3000	0.6800	25.0	6.23	5.86	1.600	2.200	0.878	0.71	0.138	0.441
15.0	0.3400	0.8300	15.0	6.86	6.21	2.000	3.667	1.409	0.81	0.166	0.410
15.0	0.4200	1.0200	10.0	7.60	6.90	6.000	6.000	2.487	1.00	0.205	0.412
15.0	0.4200	1.2500	5.0	8.24	6.75	0.000	13.000	3.805	1.00	0.240	0.336

Table LXXIII
SURFACE FLAW SPECIMEN 75-19

SURFACE FLAW SPECIMEN 7475-T7351 75-19
TEMPERATURE RT T-S DIRECTION
ENVIRONMENT 3.5% NACL 60 CPM
YIELD STRENGTH 60100 PSI R = 0.30
B = 0.4370 INCH W = 2.9020 INCHES

P MAX KIPS	A INCH	2C INCH	DN X1000	DELTA K CENTER KSI/ INCH	DELTA K SURFACE KSI/ INCH	DA/DN -MICROINCHES/CYCLE-	DC/DN -MICROINCHES/CYCLE-	D(A/Q) DN -MICROINCHES/CYCLE-	A/B	A/Q	A/2C
0.0	0.0560	0.1980	0.0	0.00	0.00				0.13	0.036	0.283
15.0	0.0590	0.2070	25.7	3.13	2.36	0.117	0.175	0.075	0.14	0.038	0.285
15.0	0.0670	0.2340	40.0	3.33	2.52	0.200	0.338	0.124	0.15	0.043	0.286
15.0	0.0700	0.2450	25.0	3.41	2.58	0.120	0.220	0.079	0.16	0.045	0.286
15.0	0.0770	0.2700	50.0	3.57	2.70	0.140	0.250	0.090	0.18	0.049	0.285
15.0	0.0800	0.2800	25.0	3.64	2.75	0.120	0.200	0.074	0.18	0.051	0.286
15.0	0.0960	0.3380	50.0	4.00	3.01	0.320	0.580	0.208	0.22	0.061	0.284
15.0	0.2150	0.4720	27.7	4.99	4.77	2.671	1.372	0.666	0.49	0.096	0.456
15.0	0.2180	0.4800	5.0	5.04	4.80	0.600	0.800	0.320	0.50	0.097	0.454
15.0	0.2280	0.5000	8.0	5.14	4.91	1.250	1.250	0.510	0.52	0.101	0.456
15.0	0.2750	0.6160	12.5	5.70	5.39	2.080	2.560	1.029	0.63	0.125	0.446
15.0	0.2850	0.6380	2.0	5.80	5.48	5.000	5.500	2.230	0.65	0.129	0.447
15.0	0.3010	0.6750	1.5	5.97	5.64	10.667	12.333	4.980	0.69	0.137	0.446
15.0	0.3470	0.7720	3.0	6.38	6.05	7.333	7.833	3.183	0.79	0.156	0.449
15.0	0.3610	0.8040	1.5	6.51	6.17	9.333	10.667	4.312	0.83	0.163	0.449
15.0	0.3700	0.8250	1.0	6.60	6.25	9.000	10.500	4.238	0.85	0.167	0.448
15.0	0.4360	0.9580	0.6	7.11	6.79	60.000	58.333	23.868	1.00	0.194	0.455

Table LXXIV

SURFACE FLAW SPECIMEN 75-20

SURFACE FLAW SPECIMEN 7475-T7351 75-20
TEMPERATURE RT T-S DIRECTION
ENVIRONMENT 3.5% NACL 60CPM
YIELD STRENGTH 60100 PSI R = 0.30
B = 0.3524 INCH W = 2.9010 INCHES

P MAX KIPS	A INCH	2C INCH	DN X1000	DELTA K CENTER KSI/ INCH	DELTA K SURFACE KSI/ INCH	DA/DN -MICROINCHES/CYCLE-	DC/DN -MICROINCHES/CYCLE-	D(A/Q)/DN -MICROINCHES/CYCLE-	A/B	A/Q	A/2C
0.0	0.0650	0.2470	0.0	0.00	0.00				0.18	0.044	0.263
12.0	0.0688	0.2530	20.0	3.43	2.53	0.190	0.150	0.071	0.20	0.046	0.272
12.0	0.0750	0.2630	30.0	3.50	2.64	0.207	0.167	0.064	0.21	0.048	0.285
12.0	0.0819	0.2740	26.0	3.61	2.79	0.265	0.212	0.111	0.23	0.051	0.299
12.0	0.0974	0.2970	50.0	3.81	3.09	0.310	0.230	0.120	0.28	0.057	0.328
12.0	0.1469	0.3600	100.0	4.30	3.89	0.495	0.315	0.155	0.42	0.072	0.408

Table LXXV
SURFACE FLAW SPECIMEN 75-25

SURFACE FLAW SPECIMEN 7475-T7351 75-25
TEMPERATURE RT L-S DIRECTION
ENVIRONMENT 3.5%NACL 6 CPM
YIELD STRENGTH 61700 PSI R = 0.30
B = 0.4220 INCH W = 2.9000 INCHES

P MAX KIPS	A INCH	2C INCH	DN X1000	DELTA K CENTER KSI/ INCH	DELTA K SURFACE KSI/ INCH	DA/DN -MICROINCHES/CYCLE-	DC/DN -MICROINCHES/CYCLE-	D(A/Q) DN	A/B	A/Q	A/2C
0.0	0.0800	0.1590	0.0	0.00	0.00				0.19	0.032	0.503
22.0	0.0900	0.1800	15.1	4.70	4.70	0.661	0.694	0.285	0.21	0.037	0.500
22.0	0.1280	0.2560	31.9	5.61	5.61	1.191	1.191	0.486	0.30	0.052	0.500
22.0	0.1650	0.3320	16.6	6.39	6.37	2.235	2.295	0.937	0.39	0.068	0.497
22.0	0.2530	0.5490	7.0	8.21	7.88	6.183	7.980	3.232	0.60	0.112	0.461
22.0	0.3470	0.8280	2.1	10.04	9.19	18.777	30.091	11.831	0.82	0.167	0.419
22.0	0.3870	0.9790	0.8	10.87	9.66	32.500	64.375	24.401	0.92	0.196	0.395
22.0	0.4140	1.0950	0.3	11.45	9.95	53.333	116.667	42.922	0.98	0.218	0.378
22.0	0.4220	1.1360	0.2	11.64	10.03	40.000	102.500	36.652	1.00	0.225	0.371

CENTER CRACK TENSION

P MAX KIPS	dN CYCLES	2C FRONT	2C REAR INCHES	2C AVG.	da/dN x 10^{-6}	ΔK KSI-$\sqrt{\text{IN}}$
22	200	1.178	.519	.848	-	-
	100	1.199	.565	.882	170	15.7
	100	1.224	.637	.931	245	16.3
	100	1.258	.714	.986	275	16.9
	214	1.332	.864	1.098	262	18.2
	200	1.407	1.037	1.222	310	19.6
	200	1.515	1.206	1.360	345	21.4
	300	1.654	1.437	1.545	308	24.0
	200	1.803	1.705	1.754	523	27.4
	124	2.130	1.980	2.055	1210	34.0

Table LXXVI
SURFACE FLAW SPECIMEN 8-17

SURFACE FLAW SPECIMEN TI-8MO-8V-2FE-3AL 8-17
TEMPERATURE RT L-S DIRECTION
ENVIRONMENT DRY AIR 360 CPM
YIELD STRENGTH 169700 PSI R = 0.30
B = 0.5015 INCH W = 3.0120 INCHES

P MAX KIPS	A INCH	2C INCH	DN X1000	DELTA K CENTER KSI/ INCH	DELTA K SURFACE KSI/ INCH	DA/DN -MICROINCHES/CYCLE-	DC/DN	D(A/Q) DN	A/B	A/Q	A/2C
0.0	0.1420	0.3590	0.0	0.00	0.00				0.28	0.071	0.396
20.0	0.1570	0.3930	100.4	5.05	4.52	0.149	0.169	0.069	0.31	0.078	0.400
20.0	0.1680	0.4210	72.1	5.23	4.67	0.153	0.194	0.077	0.34	0.084	0.399
20.0	0.1810	0.4500	66.3	5.41	4.85	0.196	0.219	0.089	0.36	0.090	0.402
20.0	0.1830	0.4520	20.0	5.43	4.88	0.100	0.050	0.025	0.37	0.090	0.405
20.0	0.2340	0.5730	100.3	6.11	5.53	0.329	0.379	0.153	0.47	0.114	0.408
20.0	0.2490	0.6070	35.1	6.29	5.70	0.427	0.484	0.196	0.50	0.121	0.410
20.0	0.2890	0.6970	33.7	6.75	6.15	0.505	0.564	0.228	0.58	0.140	0.415
20.0	0.3100	0.7410	23.9	6.96	6.37	0.880	0.922	0.377	0.62	0.148	0.418
20.0	0.3540	0.8390	50.1	7.41	6.81	0.879	0.979	0.396	0.71	0.168	0.422
20.0	0.4020	0.9410	13.2	7.86	7.26	1.519	1.633	0.663	0.80	0.189	0.427
20.0	0.4250	0.9940	14.3	8.08	7.47	1.605	1.849	0.744	0.85	0.200	0.428
20.0	0.4790	1.1040	10.0	8.52	7.94	2.700	2.850	1.158	0.96	0.222	0.434
20.0	0.4970	1.1430	8.0	8.67	8.08	2.250	2.437	0.988	0.99	0.230	0.435

Table LXXVII
SURFACE FLAW SPECIMEN 8-39

SURFACE FLAW SPECIMEN TI-8MO-8V-2FE-3AL 8-39
TEMPERATURE RT T-S DIRECTION
ENVIRONMENT DRY AIR 360 CPM
YIELD STRENGTH 177000 PSI R = 0.30
B = 0.4980 INCH W = 3.0080 INCHES

P MAX KIPS	A INCH	2C INCH	DN X1000	DELTA K CENTER KSI/ INCH	DELTA K SURFACE KSI/ INCH	DA/DN -MICROINCHES/CYCLE-	DC/DN -MICROINCHES/CYCLE-	D(A/Q) DN -MICROINCHES/CYCLE-	A/B	A/Q	A/2C
0.0	0.1600	0.3920	0.0	0.00	0.00				0.32	0.078	0.408
20.0	0.1710	0.4180	20.0	5.27	4.76	0.550	0.650	0.263	0.34	0.083	0.409
20.0	0.1750	0.4270	15.1	5.32	4.82	0.265	0.298	0.121	0.35	0.085	0.410
20.0	0.1790	0.4370	20.2	5.38	4.87	0.198	0.247	0.098	0.36	0.087	0.410
20.0	0.1840	0.4490	20.0	5.46	4.94	0.250	0.300	0.120	0.37	0.090	0.410
18.0	0.1890	0.4610	50.3	4.98	4.51	0.099	0.119	0.048	0.38	0.092	0.410
18.0	0.2030	0.4940	101.4	5.15	4.67	0.138	0.163	0.065	0.41	0.099	0.411
18.0	0.2150	0.5210	77.3	5.29	4.81	0.155	0.175	0.071	0.43	0.104	0.413
18.0	0.2220	0.5380	45.6	5.38	4.89	0.153	0.186	0.075	0.45	0.108	0.413
18.0	0.2640	0.6320	20.4	5.84	5.33	0.295	0.295	0.121	0.53	0.127	0.418
20.0	0.2700	0.6470	20.0	6.56	5.99	0.300	0.375	0.150	0.54	0.130	0.417
20.0	0.2870	0.6850	40.1	6.75	6.18	0.424	0.474	0.192	0.58	0.137	0.419
20.0	0.2990	0.7110	24.5	6.88	6.31	0.489	0.530	0.215	0.60	0.143	0.421
22.0	0.3190	0.7560	30.6	7.81	7.17	0.653	0.735	0.297	0.64	0.152	0.422
24.0	0.3420	0.8070	20.0	8.80	8.10	1.149	1.274	0.517	0.69	0.162	0.424
26.0	0.3570	0.8390	10.0	9.73	8.97	1.500	1.600	0.653	0.72	0.169	0.426
26.0	0.3670	0.8600	5.0	9.85	9.10	2.000	2.100	0.856	0.74	0.173	0.427
30.0	0.3690	0.8660	2.0	11.40	10.53	0.985	1.478	0.606	0.74	0.174	0.426
30.0	0.3790	0.8860	3.0	11.54	10.67	3.333	3.333	1.367	0.76	0.178	0.428
30.0	0.3930	0.9170	5.0	11.74	10.87	2.800	3.100	1.255	0.79	0.184	0.429
35.0	0.4020	0.9350	2.0	13.84	12.83	4.500	4.500	1.887	0.81	0.188	0.430
35.0	0.4090	0.9530	2.0	13.97	12.94	3.500	4.500	1.792	0.82	0.192	0.429
35.0	0.4220	0.9780	2.0	14.15	13.15	6.500	6.250	2.574	0.85	0.197	0.432
35.0	0.4300	0.9950	2.0	14.28	13.27	4.000	4.250	1.728	0.86	0.200	0.432
35.0	0.4380	1.0120	2.0	14.40	13.40	4.000	4.250	1.728	0.88	0.204	0.433
35.0	0.4520	1.0410	2.0	14.61	13.61	7.000	7.250	2.956	0.91	0.210	0.434
38.0	0.4610	1.0610	2.0	16.01	14.93	4.500	5.000	2.055	0.93	0.214	0.435
38.0	0.4770	1.0930	2.0	16.26	15.19	8.000	8.000	3.274	0.96	0.220	0.436
38.0	0.4940	1.1290	2.0	16.52	15.46	8.500	9.000	3.659	0.99	0.228	0.438

Table LXXVIII

CENTER CRACK TENSION SPECIMEN TI-8MO-8V-2FE-3AL #8-39

Temperature RT T-S Direction
Dry Air, 360 CPM, R = 0.3
B = 0.498 Inch W = 3.008 Inch

P_{MAX} KIPS	dN CYCLES	2C FRONT	REAR	AVG.	da/dN x 10^{-6}	ΔK KSI-$\sqrt{\text{In.}}$
38	1000	1.175	.342	.759	-	-
38	2000	1.214	.602	.908	37.3	22.5
40	1000	1.241	.711	.976	34	24.8
40	1000	1.266	.822	1.044	34	25.9
44	1000	1.287	.973	1.130	43	30.1
44	1000	1.316	1.212	1.264	67	32.6
44	1000	1.383	1.527	1.455	95.5	36.5

Table LXXIX
SURFACE FLAW SPECIMEN 8-19

SURFACE FLAW SPECIMEN TI-8MO-8V-2FE-3AL 8-19
TEMPERATURE RT L-S DIRECTION
ENVIRONMENT 3.5% NACL 60CPM
YIELD STRENGTH 169700 PSI R = 0.30
B = 0.5050 INCH W = 3.0080 INCHES

P MAX KIPS	A INCH	2C INCH	DN X1000	DELTA K CENTER KSI/ INCH	DELTA K SURFACE KSI/ INCH	DA/DN -MICROINCHES/CYCLE-	DC/DN -MICROINCHES/CYCLE-	D(A/Q)/DN -MICROINCHES/CYCLE-	A/B	A/Q	A/2C
0.0	0.1400	0.3200	0.0	0.00	0.00				0.28	0.064	0.438
20.0	0.1460	0.3340	43.3	4.66	4.36	0.139	0.162	0.066	0.29	0.067	0.437
20.0	0.1530	0.3500	18.6	4.77	4.46	0.376	0.430	0.173	0.30	0.070	0.437
18.0	0.1630	0.3720	60.0	4.43	4.14	0.167	0.183	0.074	0.32	0.075	0.438
18.0	0.1700	0.3870	85.0	4.52	4.23	0.082	0.088	0.036	0.34	0.078	0.439
18.0	0.1820	0.4150	75.0	4.68	4.38	0.160	0.187	0.075	0.36	0.084	0.439
20.0	0.2070	0.4700	30.0	5.53	5.19	0.267	0.250	0.103	0.41	0.095	0.440
20.0	0.2120	0.4830	20.0	5.61	5.25	0.250	0.325	0.129	0.42	0.097	0.439
20.0	0.2170	0.4940	25.5	5.67	5.31	0.196	0.216	0.087	0.43	0.100	0.439
20.0	0.2270	0.5170	30.0	5.80	5.44	0.333	0.383	0.154	0.45	0.104	0.439
20.0	0.2390	0.5430	40.0	5.95	5.58	0.300	0.325	0.132	0.47	0.109	0.440
22.0	0.2710	0.6150	15.0	6.96	6.53	0.667	0.767	0.310	0.54	0.124	0.441
22.0	0.2840	0.6430	30.0	7.12	6.69	0.433	0.467	0.189	0.56	0.130	0.442
22.0	0.3010	0.6820	25.0	7.33	6.89	0.680	0.780	0.314	0.60	0.138	0.441
22.0	0.3060	0.6930	5.0	7.39	6.94	1.000	1.100	0.445	0.61	0.140	0.442
24.0	0.3510	0.7920	10.0	8.62	8.12	1.300	1.450	0.588	0.70	0.160	0.443
24.0	0.3670	0.8290	9.4	8.82	8.30	1.711	1.979	0.796	0.73	0.167	0.443
24.0	0.3790	0.8550	8.0	8.96	8.43	1.500	1.625	0.658	0.75	0.172	0.443
26.0	0.4240	0.9540	5.0	10.25	9.66	3.600	3.900	1.585	0.84	0.193	0.444
26.0	0.4420	0.9930	5.0	10.46	9.87	3.600	3.900	1.579	0.88	0.200	0.445
26.0	0.4530	1.0180	3.5	10.59	9.99	3.143	3.571	1.440	0.90	0.205	0.445

Table LXXX

CENTER CRACK TENSION SPECIMEN TI-8MO-8V-2FE-3AL #8-19

Temperature RT L-S Direction
3.5% NaCl, 60 CPM, R = 0.3
B = 0.505 Inch W = 3.008 Inch

P_{MAX} KIPS	dN CYCLES	2C FRONT	2C REAR	2C AVG.	da/dN x 10^{-6}	ΔK KSI-$\sqrt{In.}$
26	4000	1.145	.514	.830	-	-
↓	1000	1.170	.675	.923	46.5	15.3
	1000	1.243	.762	1.003	40	16.2
	497	1.245	.838	1.042	39.2	16.6
	498	1.245	.899	1.072	30	16.9
	498	1.250	.993	1.122	50.2	17.4
	500	1.252	1.054	1.153	31	17.8
	498	1.261	1.155	1.208	55.2	18.4
	498	1.295	1.276	1.286	78.3	19.3
	498	1.331	1.350	1.341	55.2	19.9
	500	1.380	1.509	1.445	104	21.2
	500	1.510	1.632	1.571	126	22.8
	350	1.675	1.820	1.748	252.9	25.4
	148	1.840	1.904	1.872	418.9	27.5

At failure $2C_{AV}$ = 2.288 Inch
$2C_{MAX}$ = 2.422 Inch

Table LXXXI
SURFACE FLAW SPECIMEN 8-38

SURFACE FLAW SPECIMEN TI-8MO-8V-2FE-3AL 8-38
TEMPERATURE RT T-S DIRECTION
ENVIRONMENT 3.5% NACL 60 CPM
YIELD STRENGTH 177000 PSI R = 0.30
B = 0.5030 INCH W = 3.0110 INCHES

P MAX KIPS	A INCH	2C INCH	DN X1000	DELTA K CENTER KSI/ INCH	DELTA K SURFACE KSI/ INCH	DA/DN -MICROINCHES/CYCLE-	DC/DN -MICROINCHES/CYCLE-	D(A/Q) DN -MICROINCHES/CYCLE-	A/B	A/Q	A/2C
0.0	0.1530	0.3050	0.0	0.00	0.00				0.30	0.062	0.502
20.0	0.1560	0.3140	20.0	4.55	4.53	0.150	0.225	0.083	0.31	0.064	0.497
20.0	0.1640	0.3350	23.3	4.70	4.65	0.343	0.451	0.182	0.33	0.068	0.490
18.0	0.1660	0.3400	18.6	4.26	4.21	0.108	0.134	0.054	0.33	0.069	0.488
18.0	0.1730	0.3600	60.0	4.38	4.30	0.117	0.167	0.067	0.34	0.073	0.481
18.0	0.1770	0.3730	25.0	4.46	4.34	0.160	0.260	0.104	0.35	0.076	0.475
18.0	0.1920	0.4200	60.0	4.73	4.52	0.250	0.392	0.156	0.38	0.085	0.457
20.0	0.2540	0.5700	75.0	6.11	5.77	0.627	0.653	0.266	0.51	0.115	0.446
22.0	0.3150	0.6960	30.0	7.44	7.07	1.233	1.300	0.528	0.63	0.141	0.453
22.0	0.3260	0.7200	10.0	7.56	7.20	1.100	1.200	0.485	0.65	0.145	0.453
24.0	0.3700	0.8180	10.0	8.79	8.36	2.000	2.300	0.929	0.74	0.165	0.452
24.0	0.3940	0.8730	10.0	9.08	8.63	2.400	2.750	1.108	0.78	0.176	0.451
24.0	0.4150	0.9220	1.0	9.33	8.86	2.000	2.000	0.815	0.83	0.186	0.450
26.0	0.4340	0.9670	5.0	10.36	9.81	3.800	4.500	1.814	0.86	0.195	0.449
26.0	0.4540	1.0160	5.0	10.61	10.03	4.000	4.900	1.964	0.90	0.205	0.447
28.0	0.4930	1.1370	2.5	12.07	11.24	5.200	11.800	4.543	0.98	0.229	0.434
28.0	0.5030	1.1800	2.0	12.29	11.35	5.000	10.750	4.102	1.00	0.237	0.426

Table LXXXII

CENTER CRACK TENSION SPECIMEN TI-8MO-8V-2FE-3AL #8-38

Temperature RT T-S Direction
3.5% NaCl, 60 CPM, R = 0.3
B = 0.5030 Inch W = 3.0110 Inches

P_{MAX} KIPS	dN CYCLES	2C FRONT	2C REAR	2C AVG.	da/dN $\times 10^{-6}$	ΔK KSI-$\sqrt{IN}$
21	2000	1.243	1.130	1.187	-	-
28	200	1.310	1.200	1.255	170	20.4
	200	1.317	1.240	1.279	60	20.7
	200	1.342	1.310	1.326	118	21.3
	200	1.395	1.362	1.379	133	22.0
	200	1.463	1.428	1.446	168	22.8
	200	1.518	1.473	1.496	125	23.5
	200	1.590	1.540	1.565	173	24.5
	200	1.668	1.628	1.648	208	25.8
	150	1.718	1.695	1.707	197	26.7
	150	1.772	1.770	1.771	213	27.8
	150	1.842	1.920	1.881	367	29.8

Table LXXXIII

CRACK PROPAGATION GROWTH RATE CONSTANTS DETERMINED FROM SURFACE

FLAW AND THROUGH CRACK CONDITIONS, R = 0.3

Surface Flaw, a/2C = .5, Valid Within da/dN = 10^{-7} to 10^{-6} Range

Environment	Cyclic Rate CPM	Crack Direction	7050 Slope M	7050 Intercept C	7475 Slope M	7475 Intercept C	Ti-8-8-2-3 Slope M	Ti-8-8-2-3 Intercept C
Dry Air	360	L-S	4.105	1.0×10^{-9}	5.071	1.5×10^{-10}	5.694	1.1×10^{-11}
"	360	T-S	*		6.104	3.8×10^{-11}	3.187	9.8×10^{-10}
3.5% NaCl	60	L-S	3.494	2.7×10^{-9}	*		3.739	4.6×10^{-10}
	60	T-S	4.995	4.5×10^{-10}	6.391	5.2×10^{-11}	3.552	8.4×10^{-10}
"	6	L-S	-	-	4.816	3.1×10^{-10}	*	
"	6	T-S	5.226	2.6×10^{-10}	*			
Center Crack Tension, Valid Within 10^{-5} to 10^{-4} Range								
Dry Air	360	T-S	-	-	-	-	2.097	4.3×10^{-8}
3.5% NaCl	60	L-S	-	-	-	-	4.236	2.6×10^{-10}
"	60	T-S	2.536	1.3×10^{-7}	-	-	2.864	1.8×10^{-8}
"	6	L-S	-	-	2.007	7.7×10^{-7}	-	-
"	6	T-S	2.275	4.2×10^{-7}	-	-	-	-

*Failed Prematurely

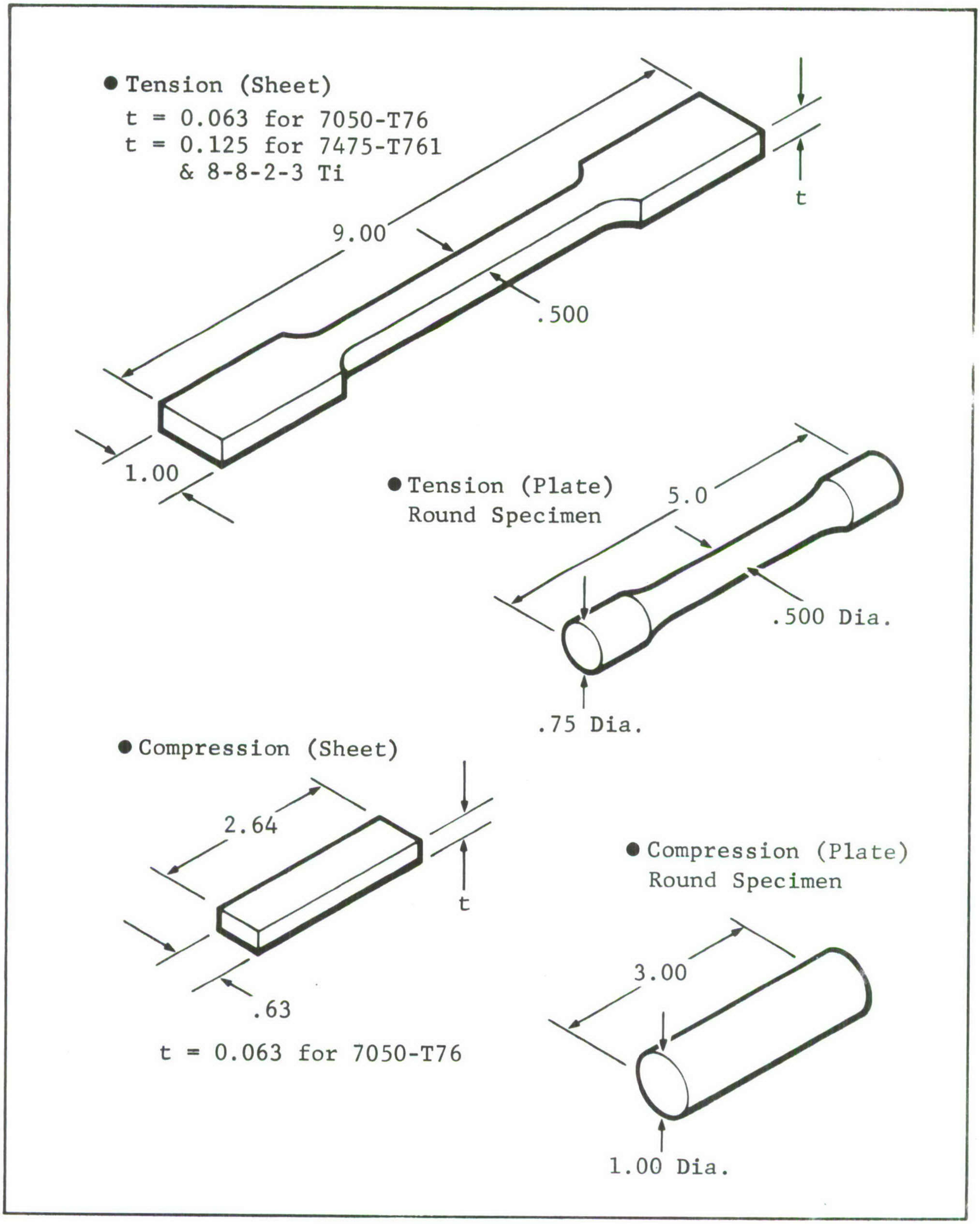
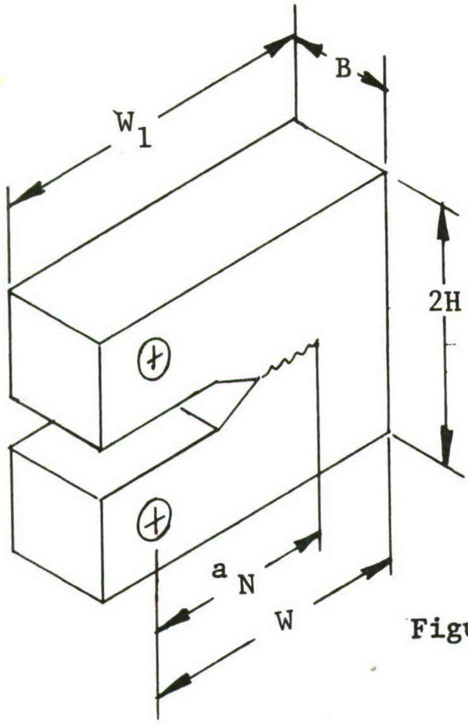
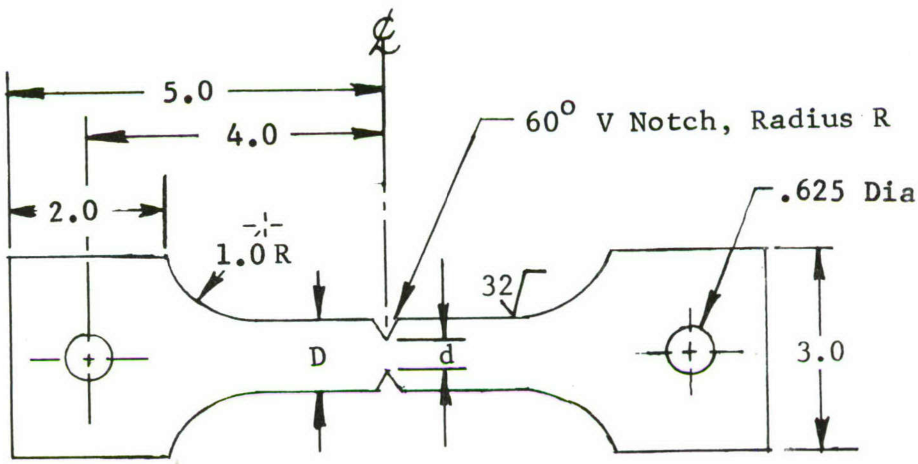


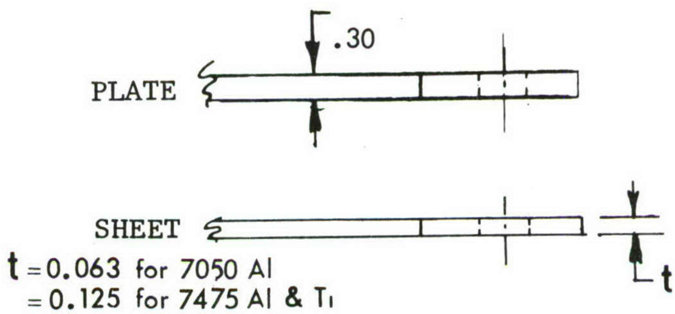
Figure 69 Tensile and Compression Test Specimens



Specimen Type & Material	Dimensions in Inches				
	B	2H	W_1	W	a_N
K_{IC} & K_{ISCC} Titanium and 7050 Plate	1.00	2.40	2.50	2.00	1.25
K_{IC} 7475-T7351 Plate	1.50	3.60	3.75	3.00	1.35

Figure 70 Compact Tension Specimen Configuration





D (±.005)	d (±.005)	R	K_T
1.000	.700	.050 ± .003	3.0
1.000	.700	.015 ±.001	5.0
1.000	.680	.145 ±.005	2.0

Figure 71 Fatigue Test Specimen Configuration

*For 8-Layer Spectrum Tests W_1 =
2.0 for 8-8-2-3
2.3 for 7050 & 7457

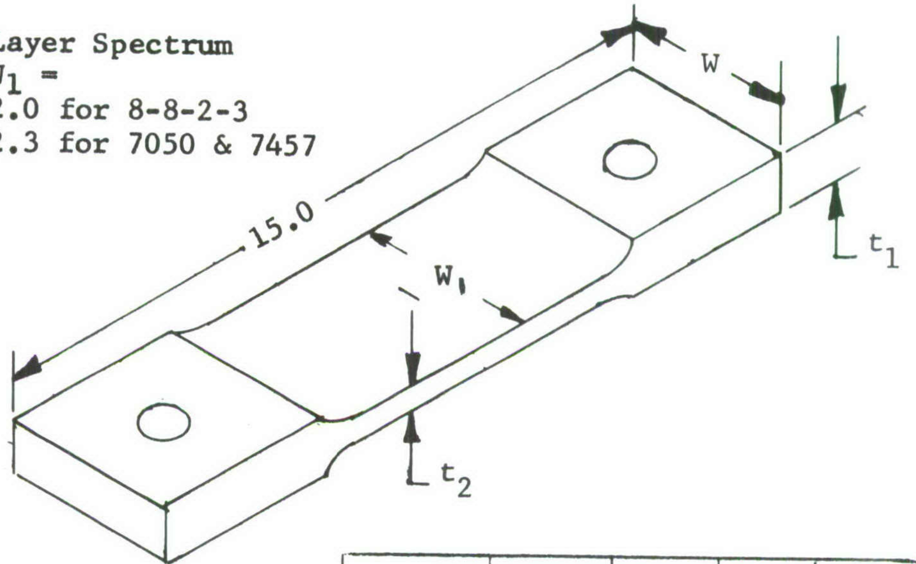


Figure 72 Surface Flaw Specimen Configuration

	t_1	t_2	W	W_1
7475	1.5	.44	3	3.0*
7050	1.4	.44	3	3.0*
8-8-2-3	1.0	.5	5	3.0*
2024	1.5	.5	5	2.9

Dimensions in inches

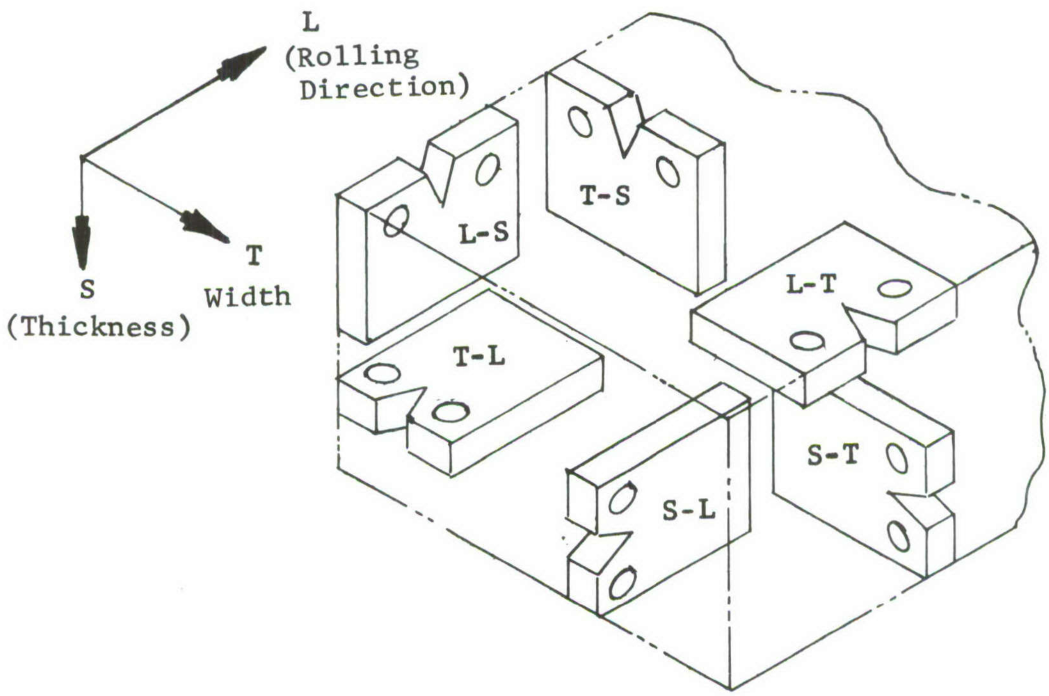


Figure 73 Fracture Mechanics Test Specimen Identification System

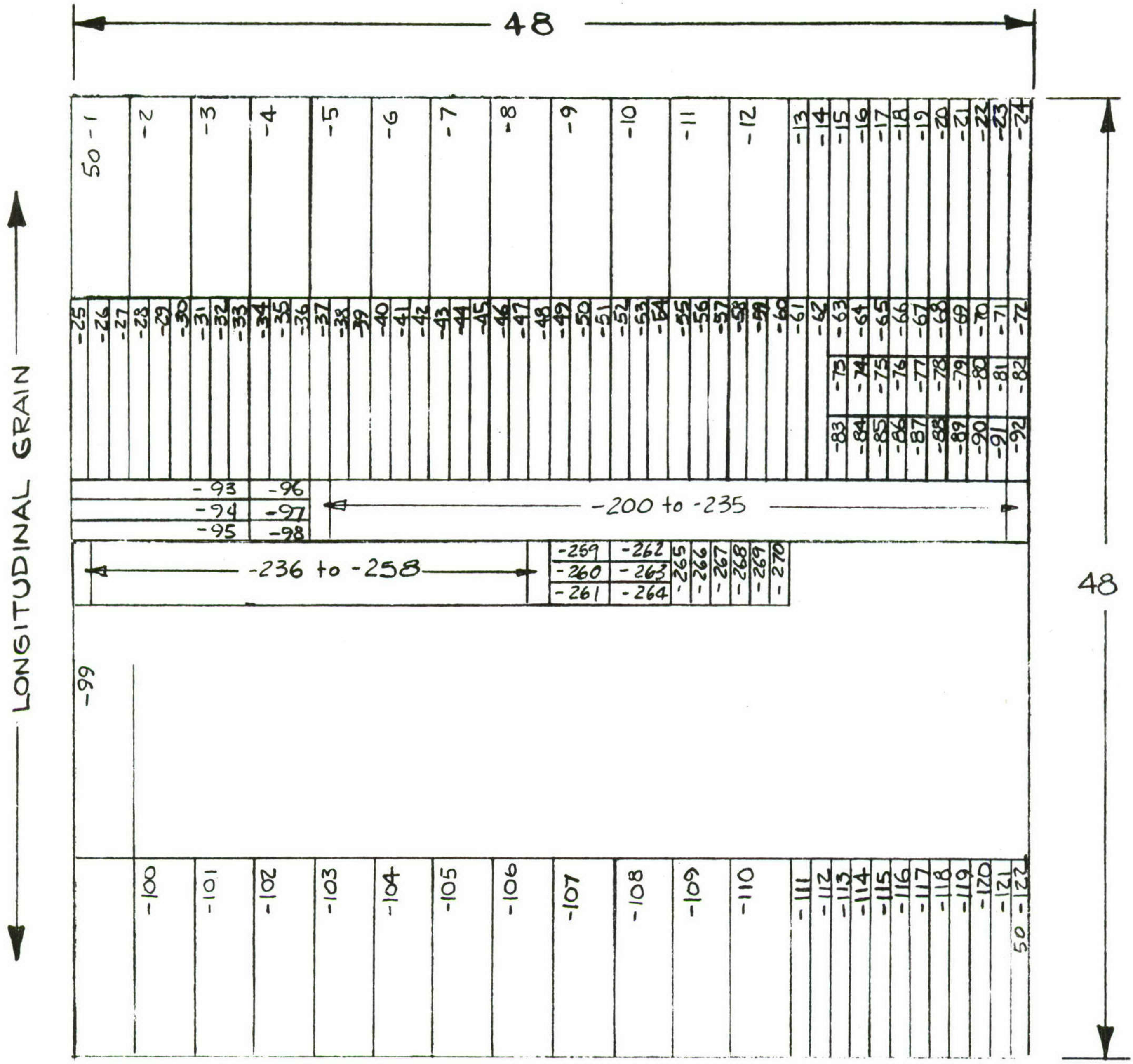


Figure 74 Specimen Locations in 7050-T76 Sheet .060" Thick

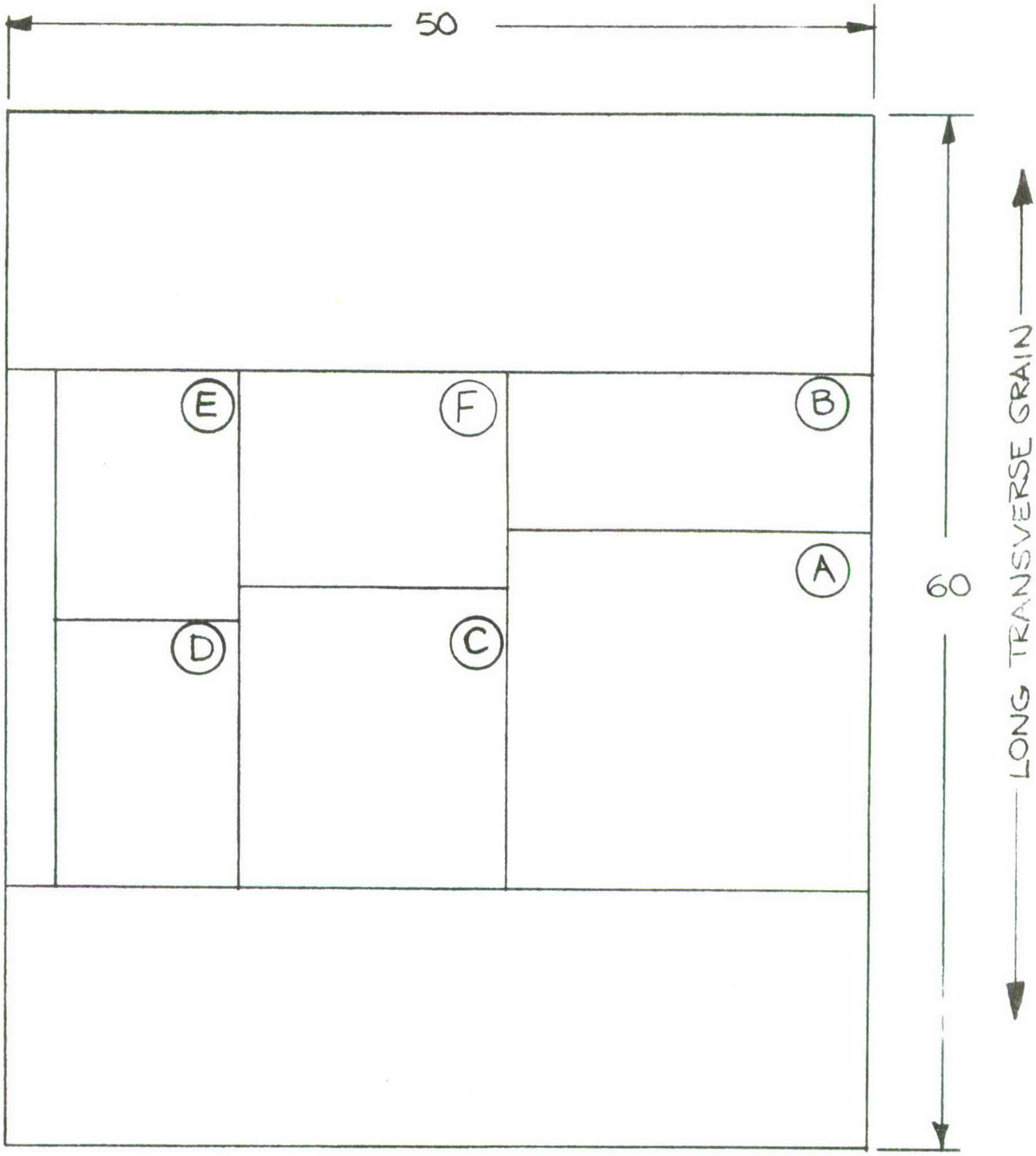


Figure 75 Detail Layout of Specimen Blanks in 7050-T73651 3" Thick Plate

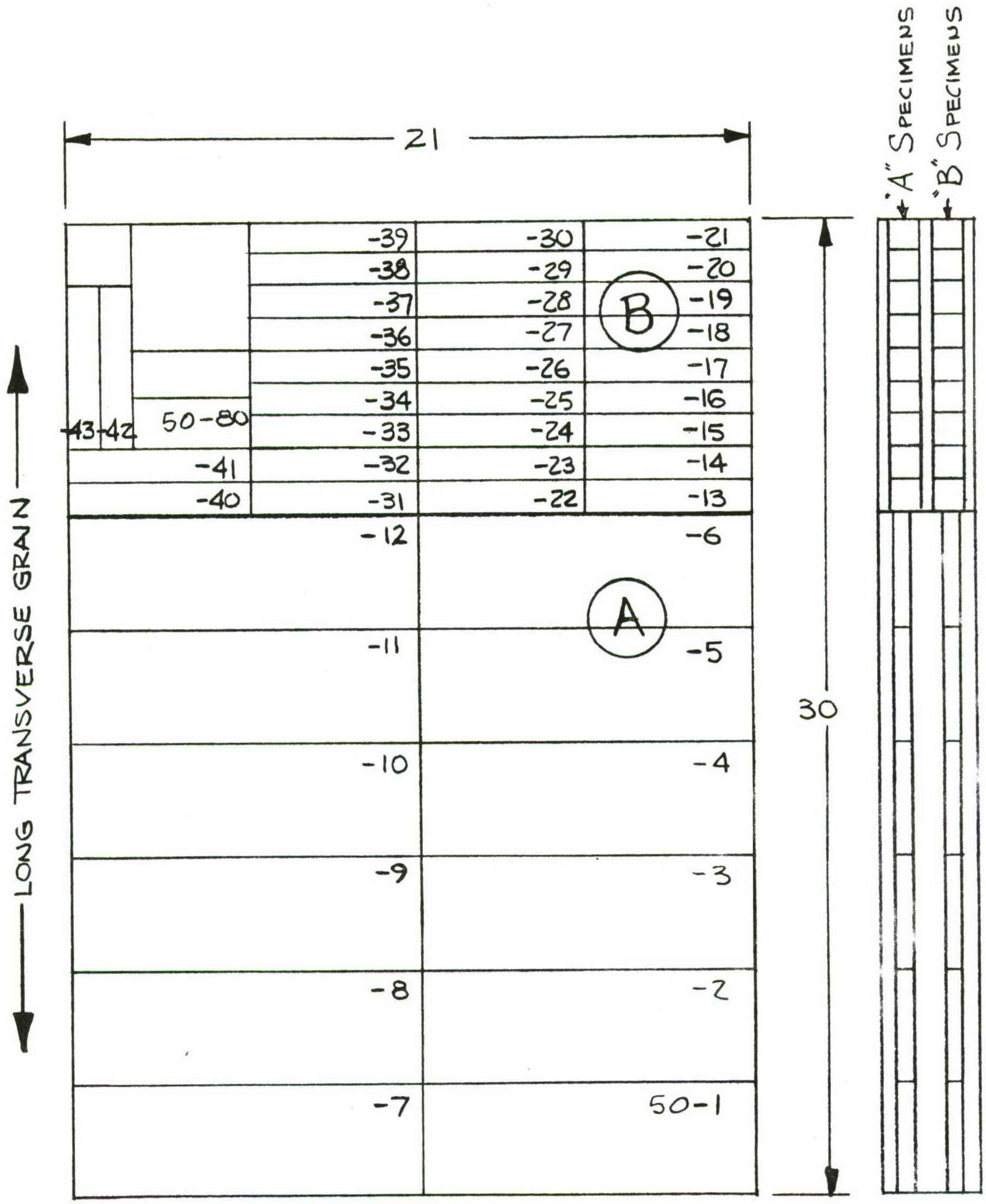


Figure 76 Specimen Location in 7050-T73651 Plate

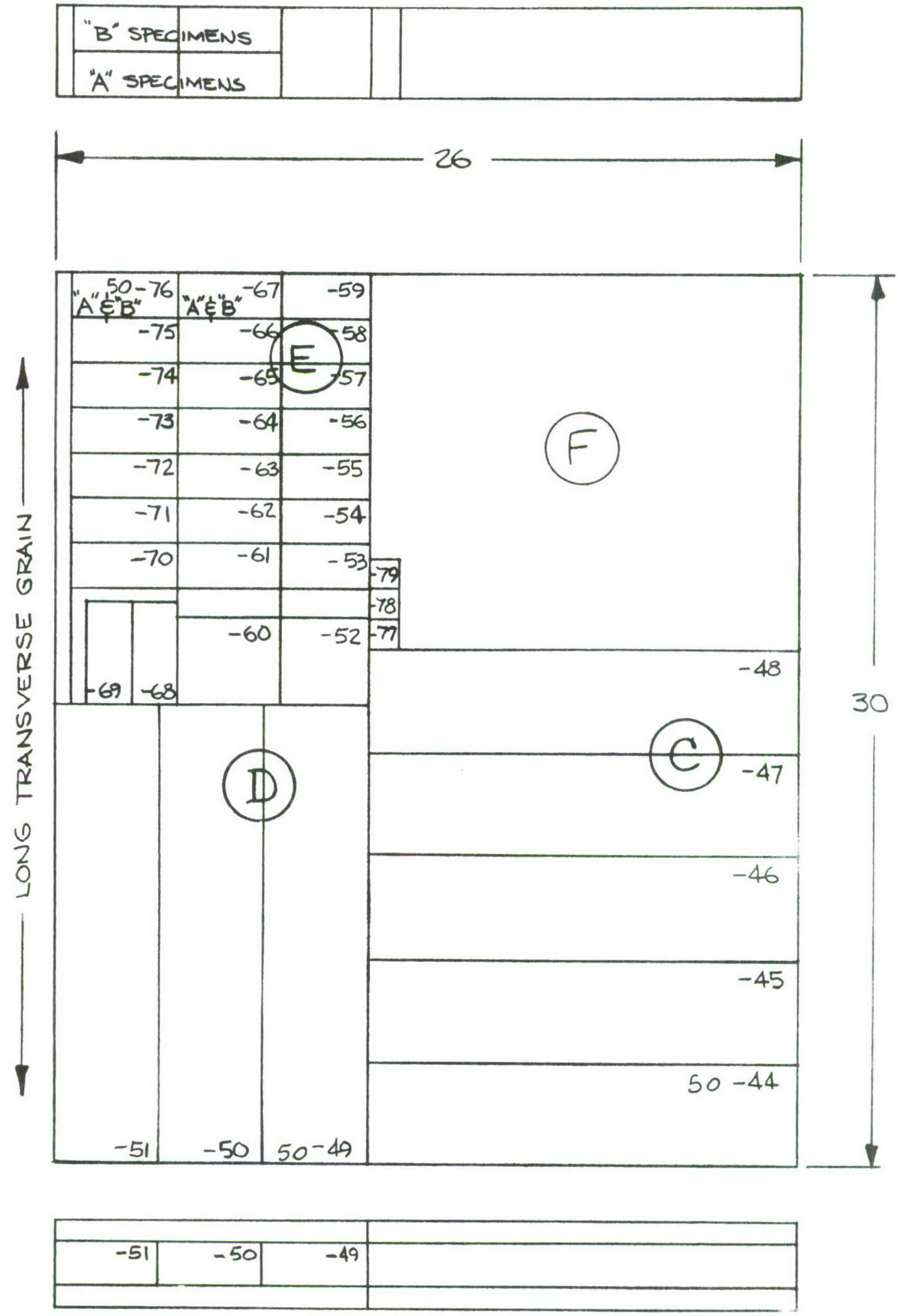


Figure 77 Specimen Location in 7050-T73651 Plate

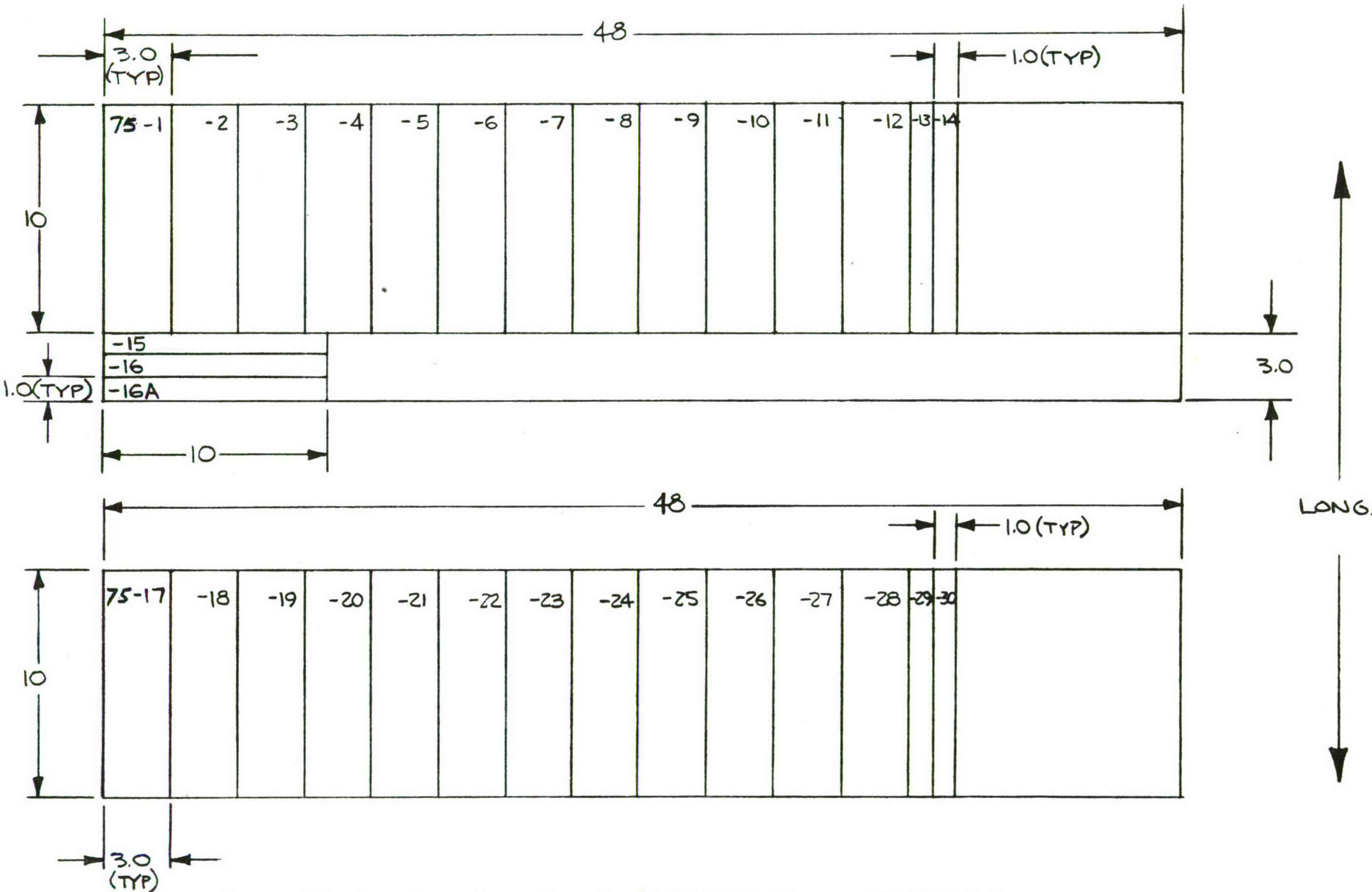


Figure 78 Specimen Location in 7475-T761 Sheet, 1/8" Thick

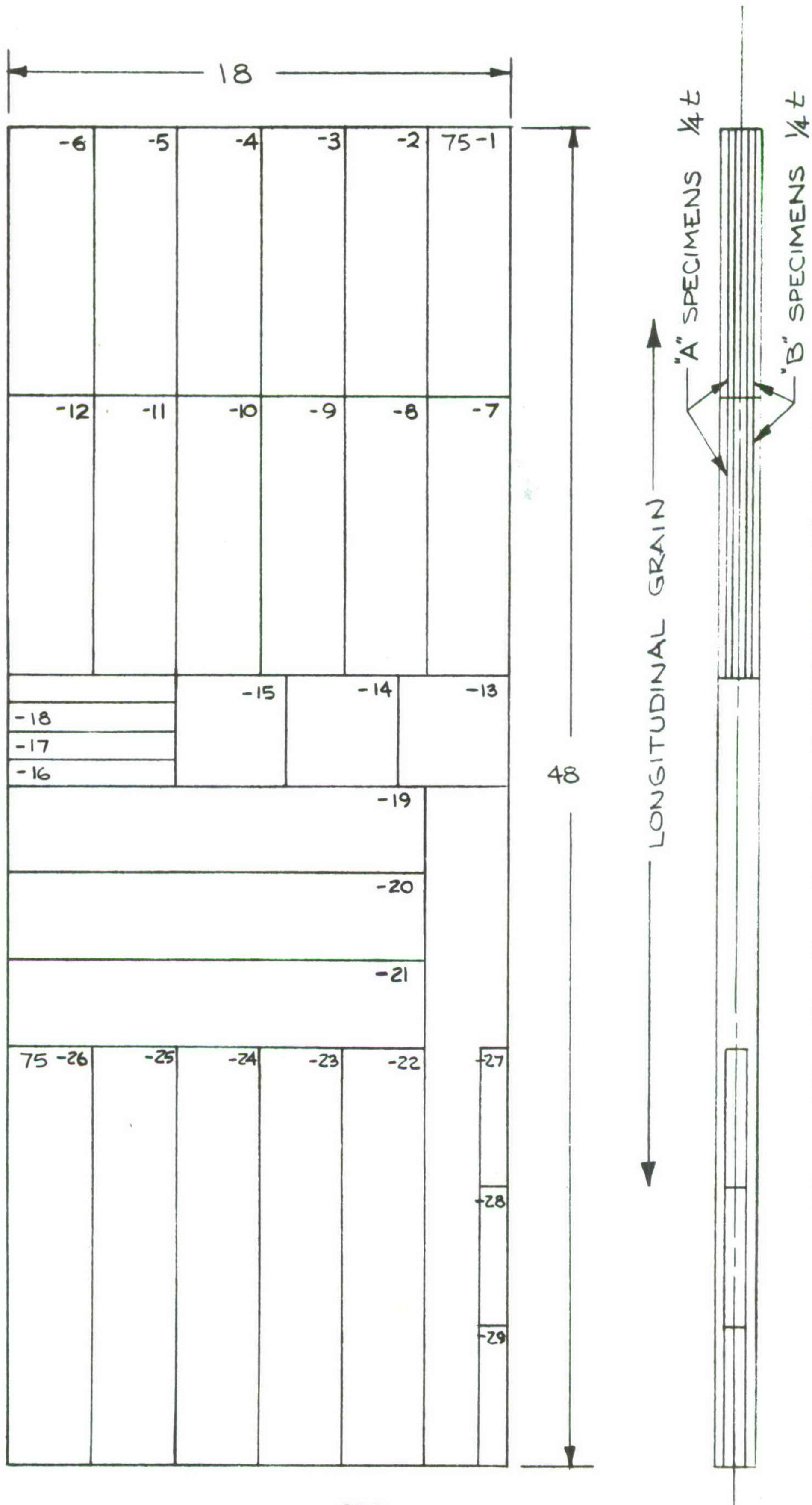


Figure 79 Specimen Location in 7475-T7351 1½ Inch Plate

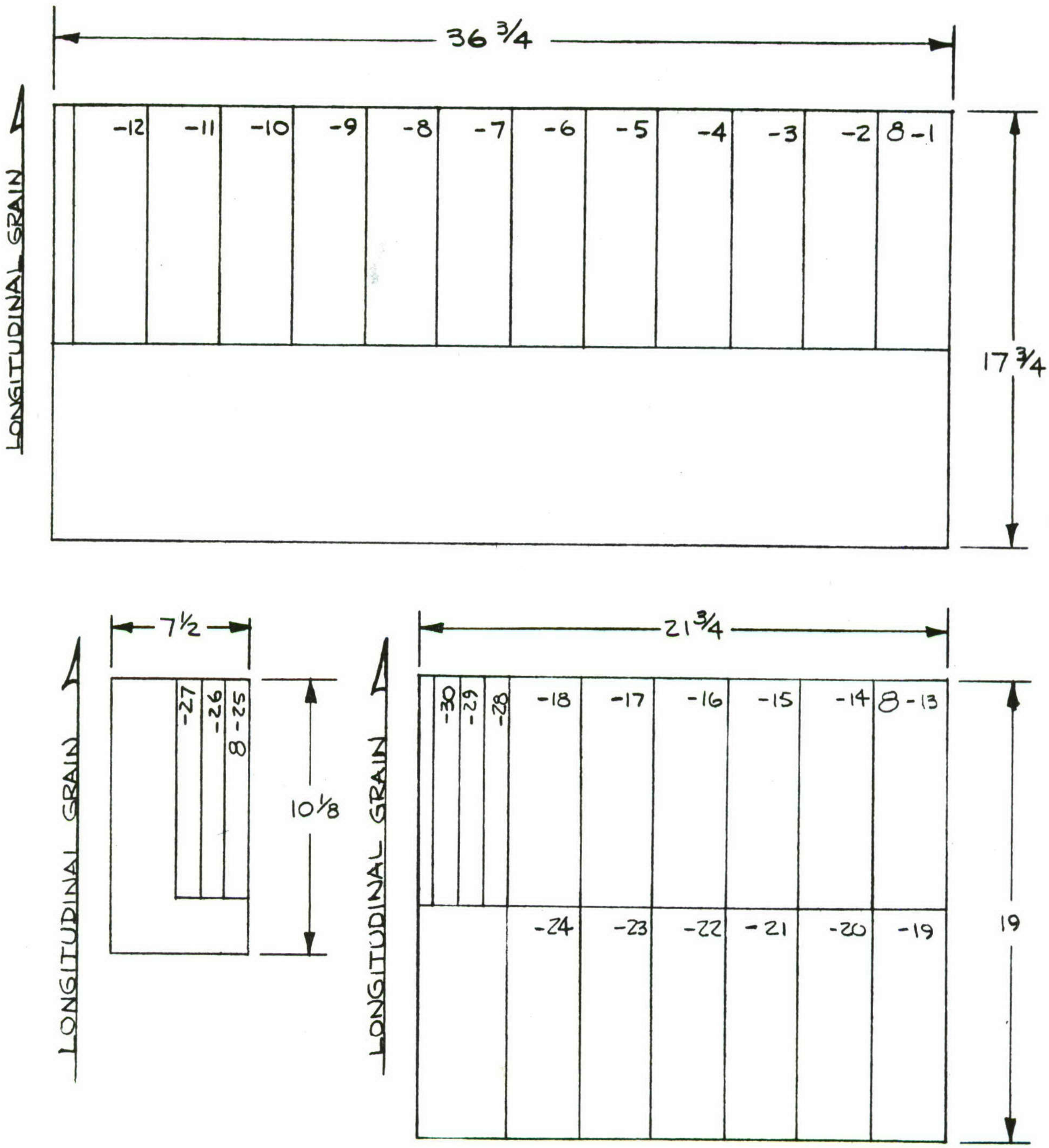


Figure 80 Specimen Layout for Ti-8Mo-8V-2Fe-3Al .125" Thick Sheet

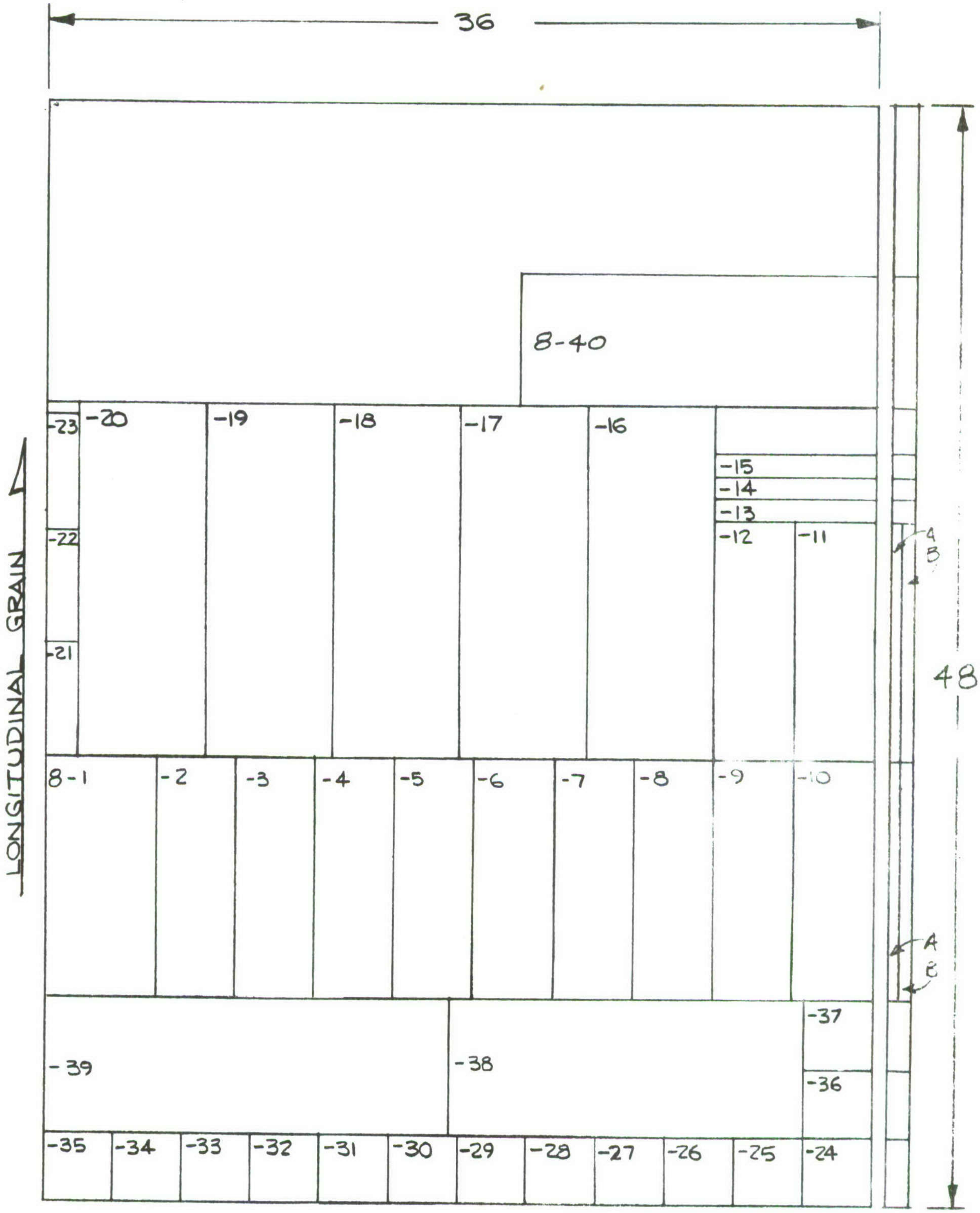


Figure 81 Specimen Layout for Ti-8Mo-8V-2Fe-3Al 1" Thick Plate

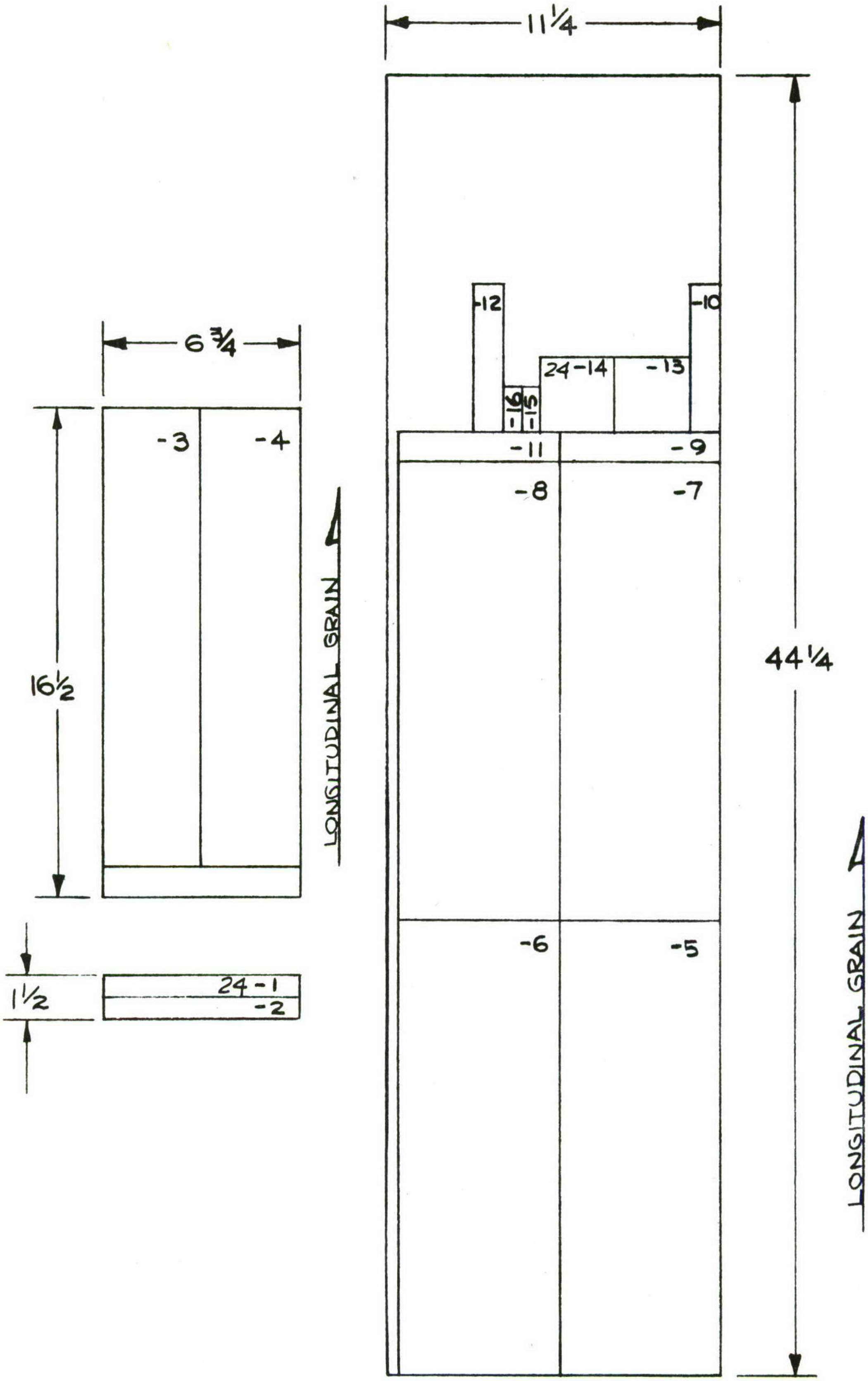


Figure 82 Specimen Location in 2024-T851 (Alcoa Lot 217-921)
FMS1010 Class A, 1½" Thick

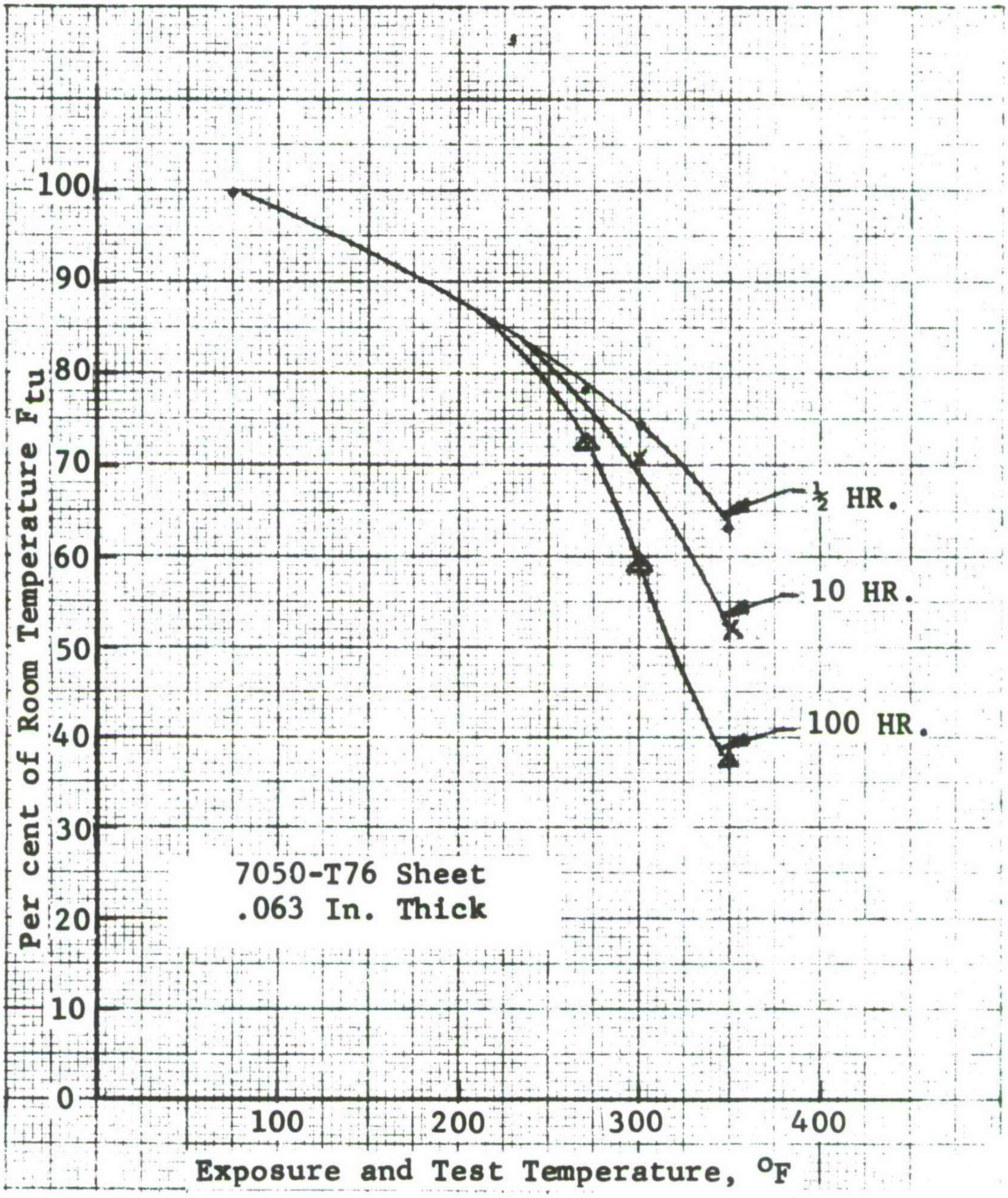


Figure 83 Effect of Elevated Temperature on the Tensile Ultimate Strength of 7050-T76 Sheet. Test at Temperature

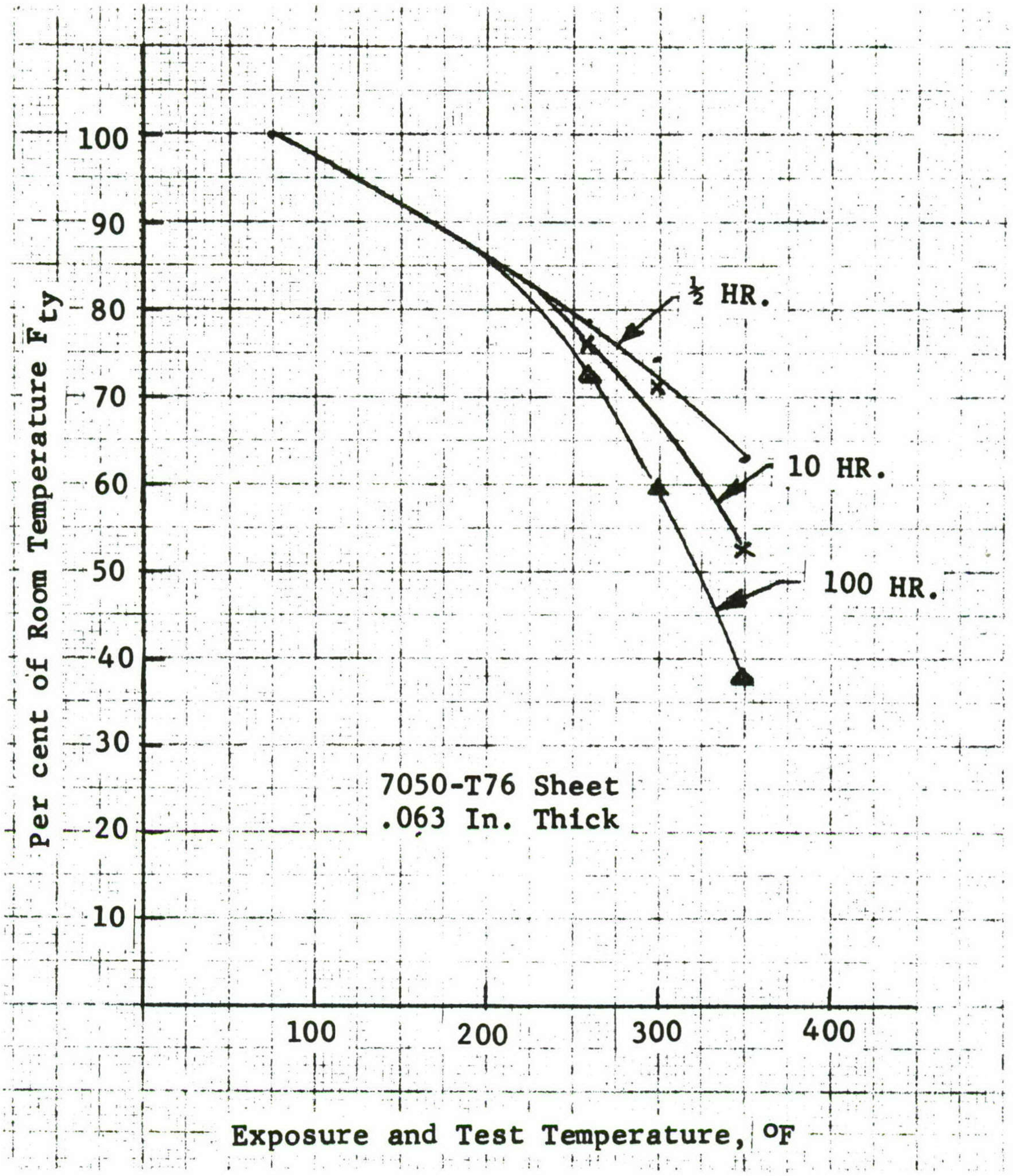


Figure 84 Effect of Elevated Temperature on the Tensile Yield Strength of 7050-T76 Sheet. Test at Temperature

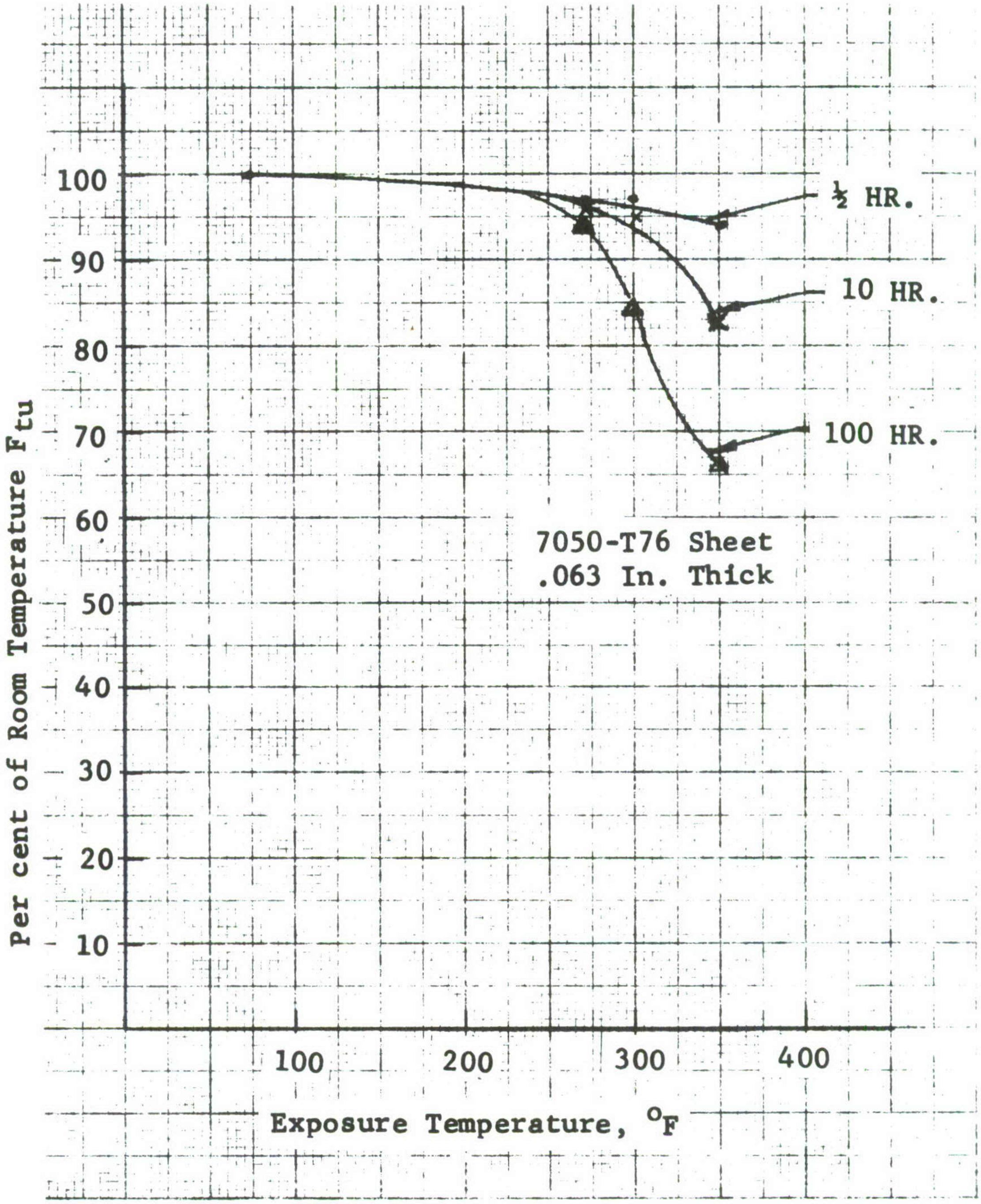


Figure 85 Effect of Elevated Temperature on the Tensile Ultimate Strength at Room Temperature After Elevated Temperature Exposure of 7050-T76 Sheet

7050-T76 Sheet
.063 In. Thick

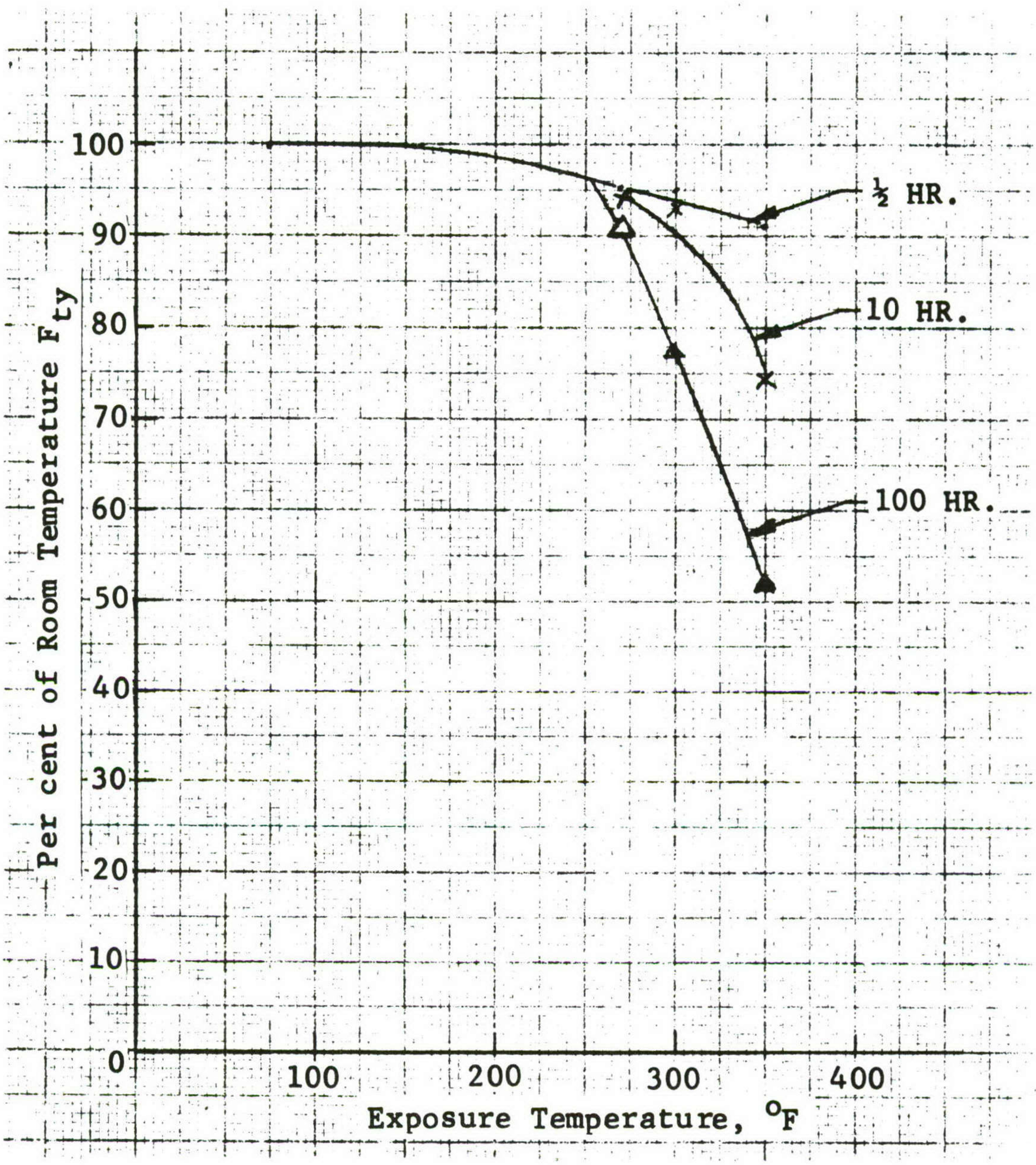


Figure 86 **Effect of Elevated Temperature on the Tensile Yield Strength at Room Temperature after Elevated Temperature Exposure of 7050-T76 Sheet**

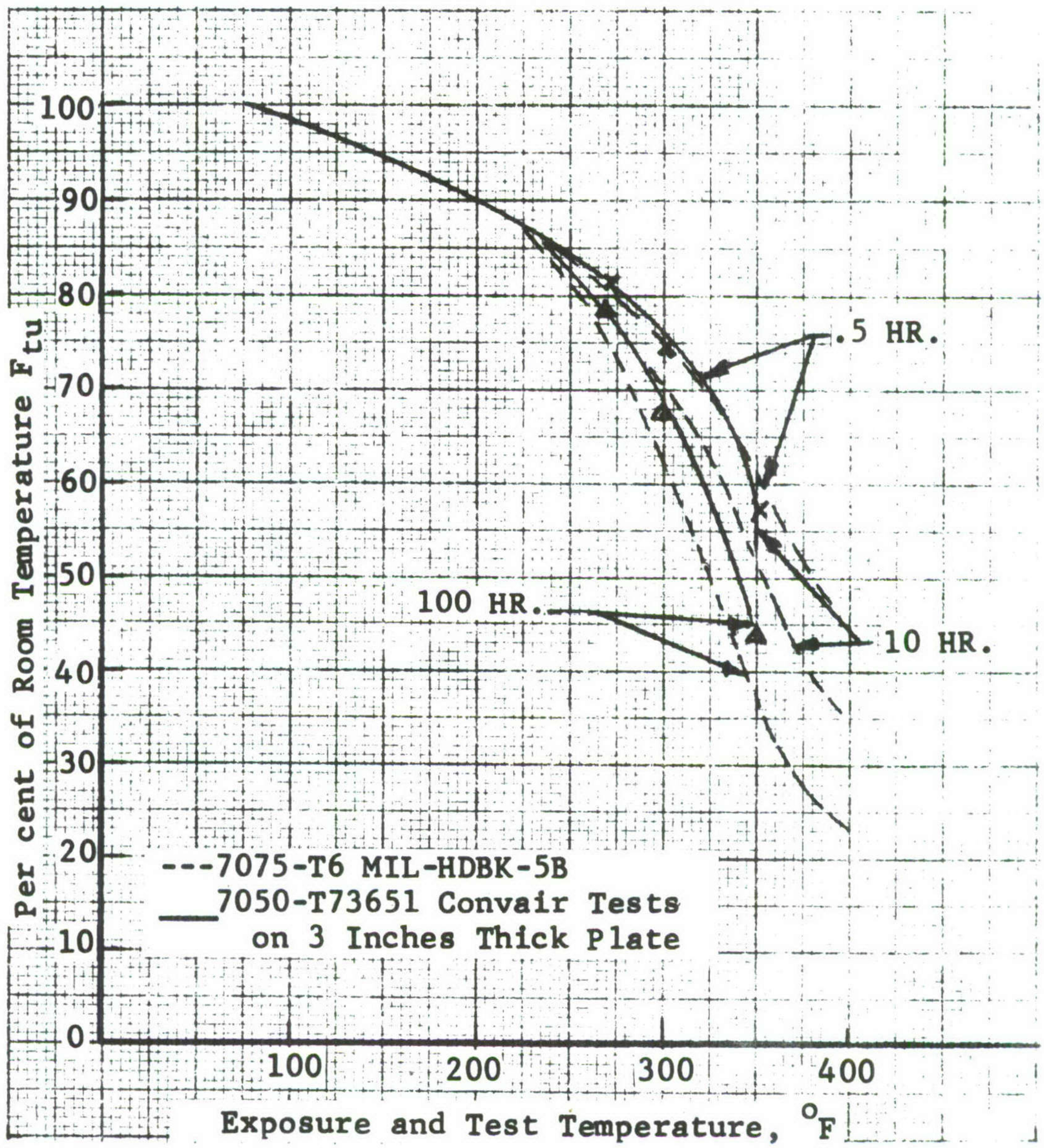


Figure 87 Effect of Elevated Temperature on the Tensile Ultimate Strength of 7050-T73651 Plate at Temperature

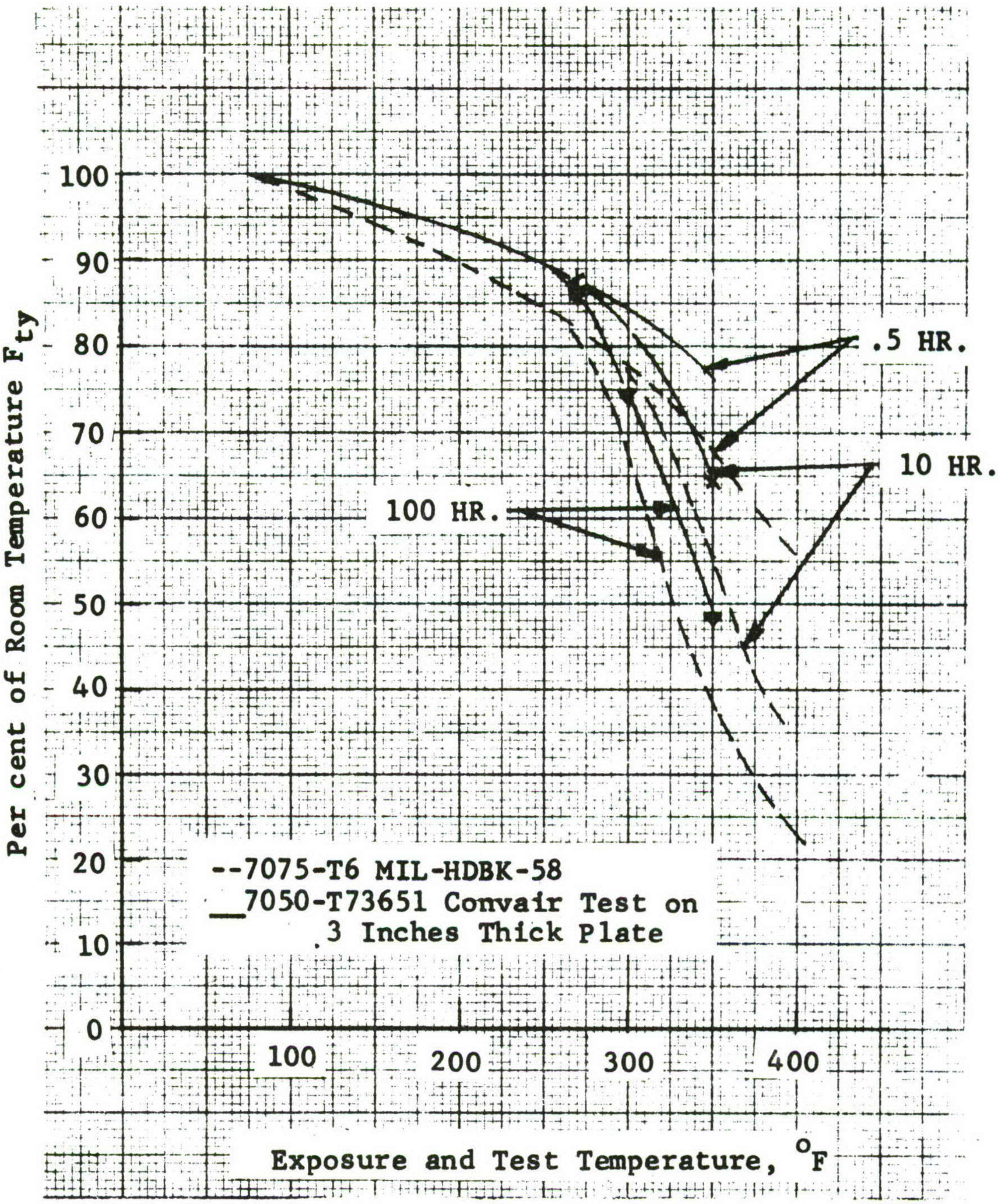


Figure 88 Effect of Elevated Temperature on the Tensile Yield Strength of 7050-T73651 Plate at Temperature

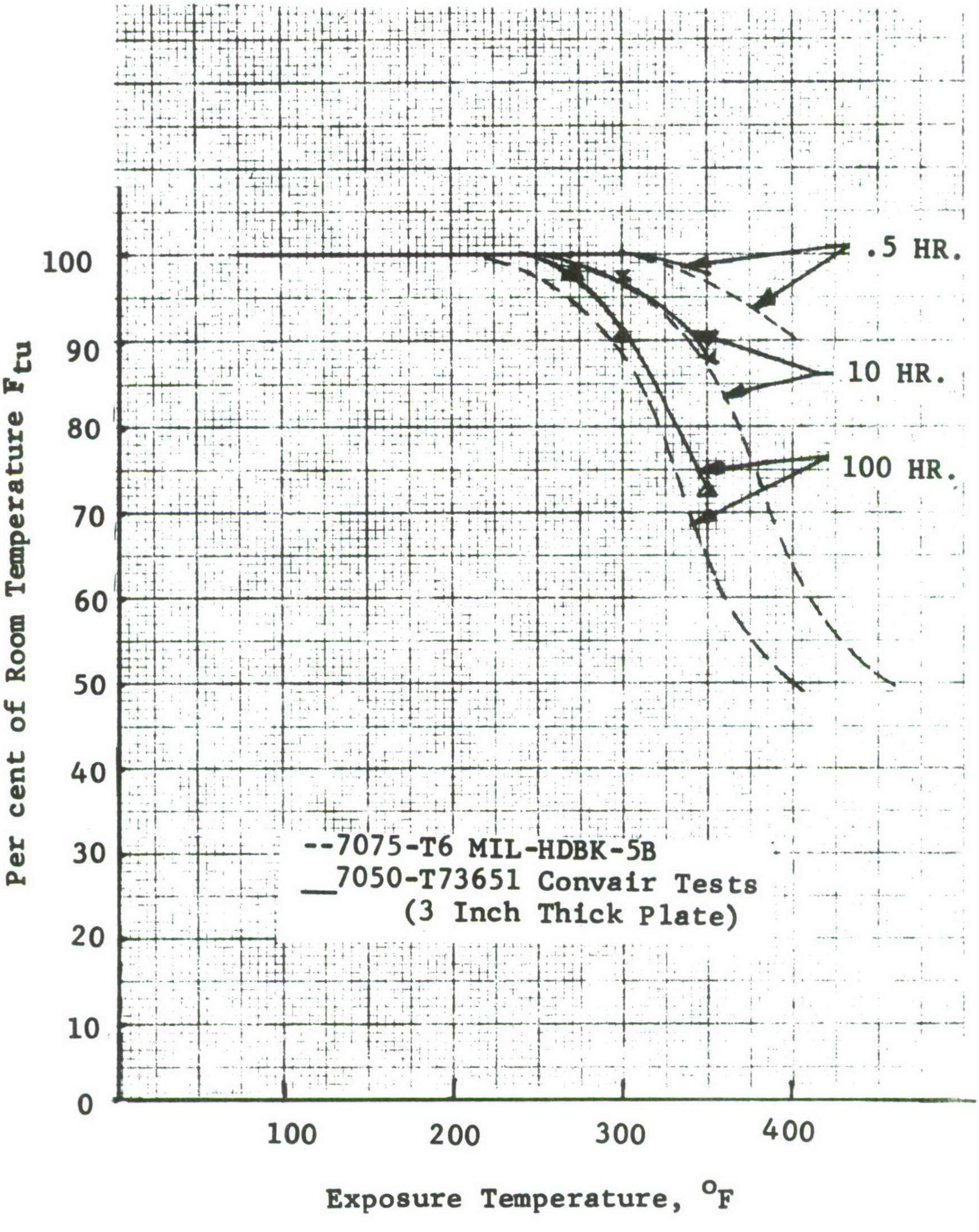


Figure 89 Effect of Elevated Temperature on the Tensile Ultimate Strength at Room Temperature after Elevated Temperature Exposure of 7050-T73651 Plate

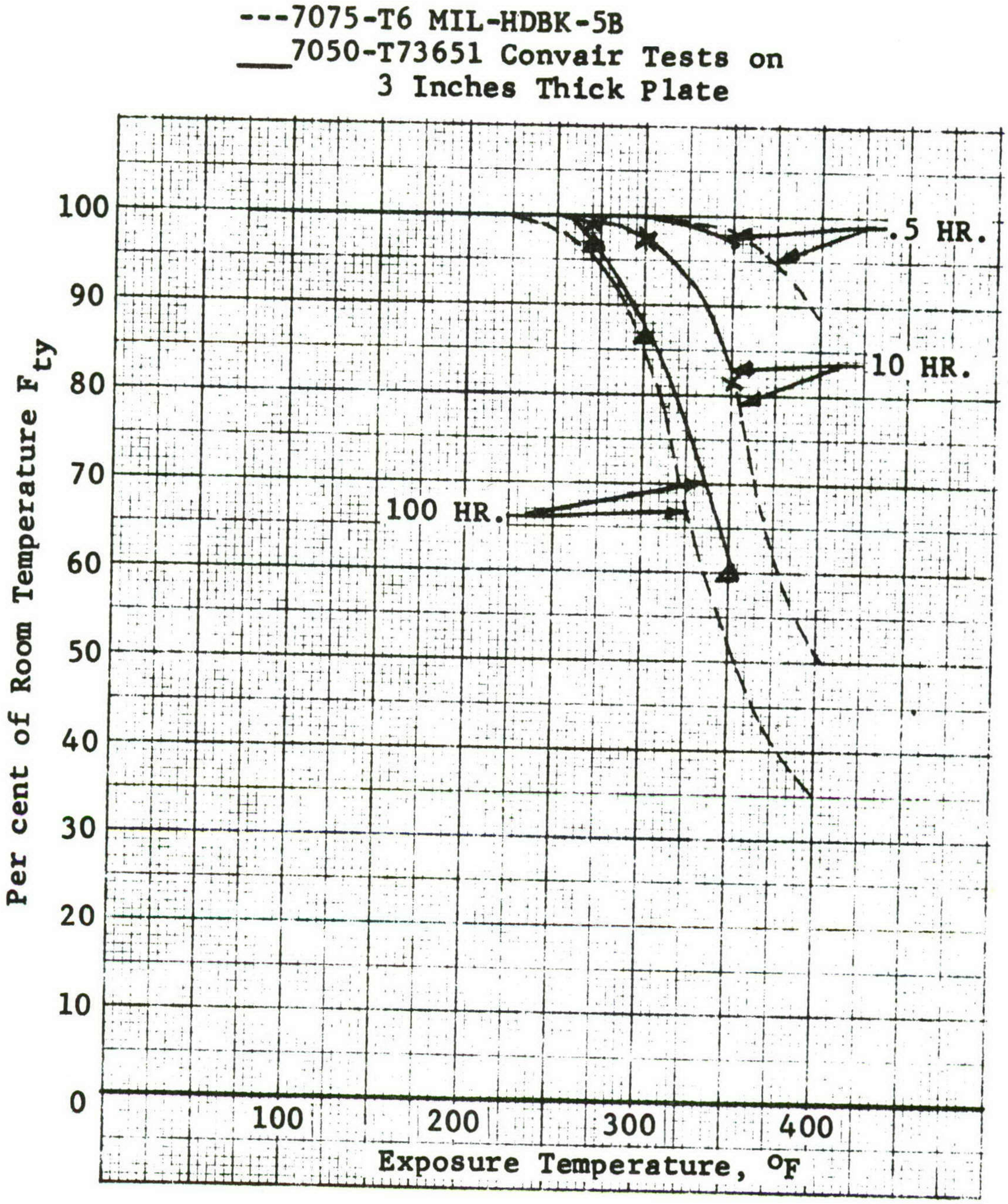


Figure 90 Effect of Elevated Temperature on the Tensile Yield Strength at Room Temperature after Elevated Temperature Exposure of 7050-T73651 Plate

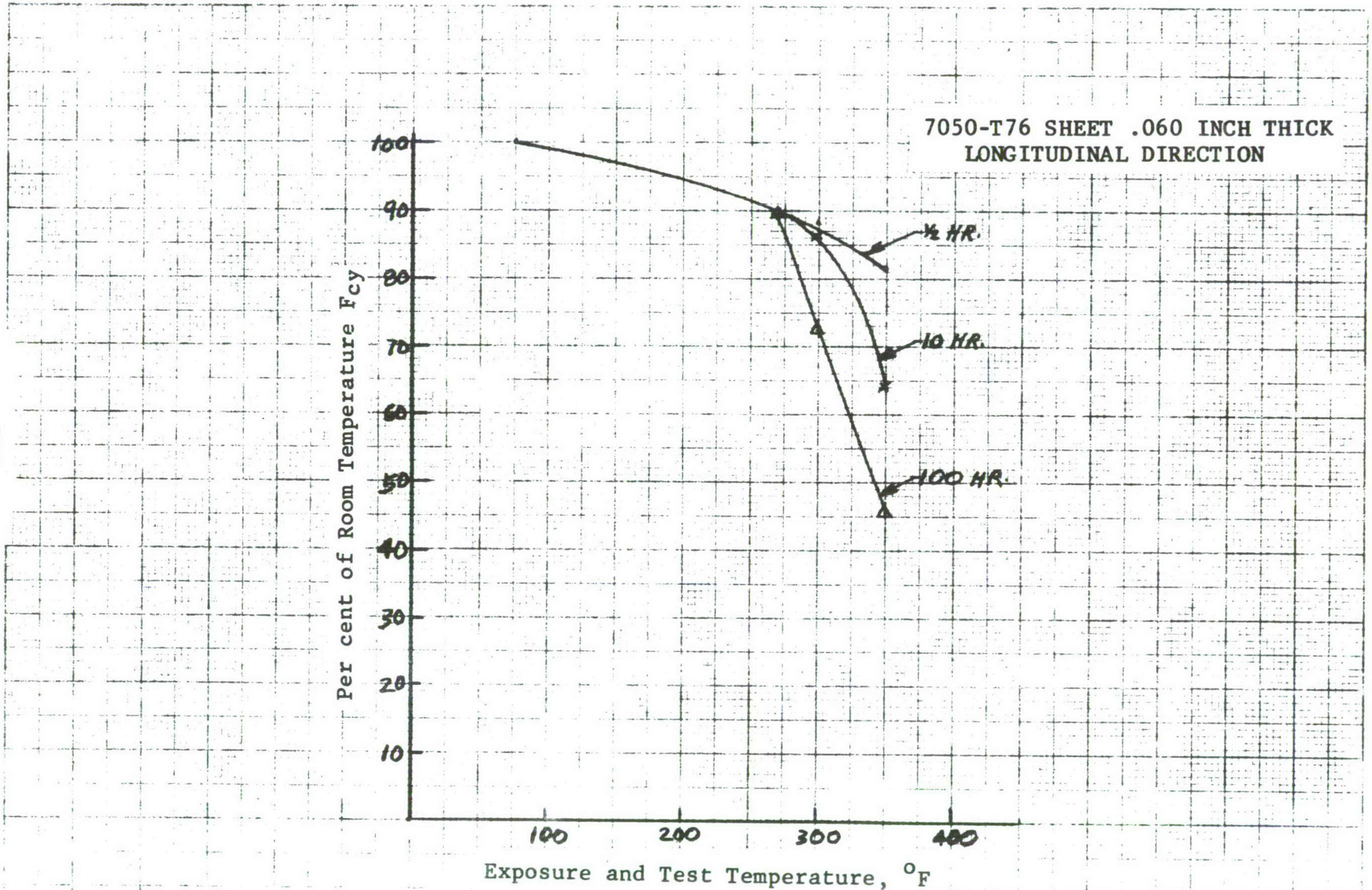


Figure 91 Effect of Elevated Temperature on the Compressive Yield Strength of 7050-T76 Sheet of Temperature

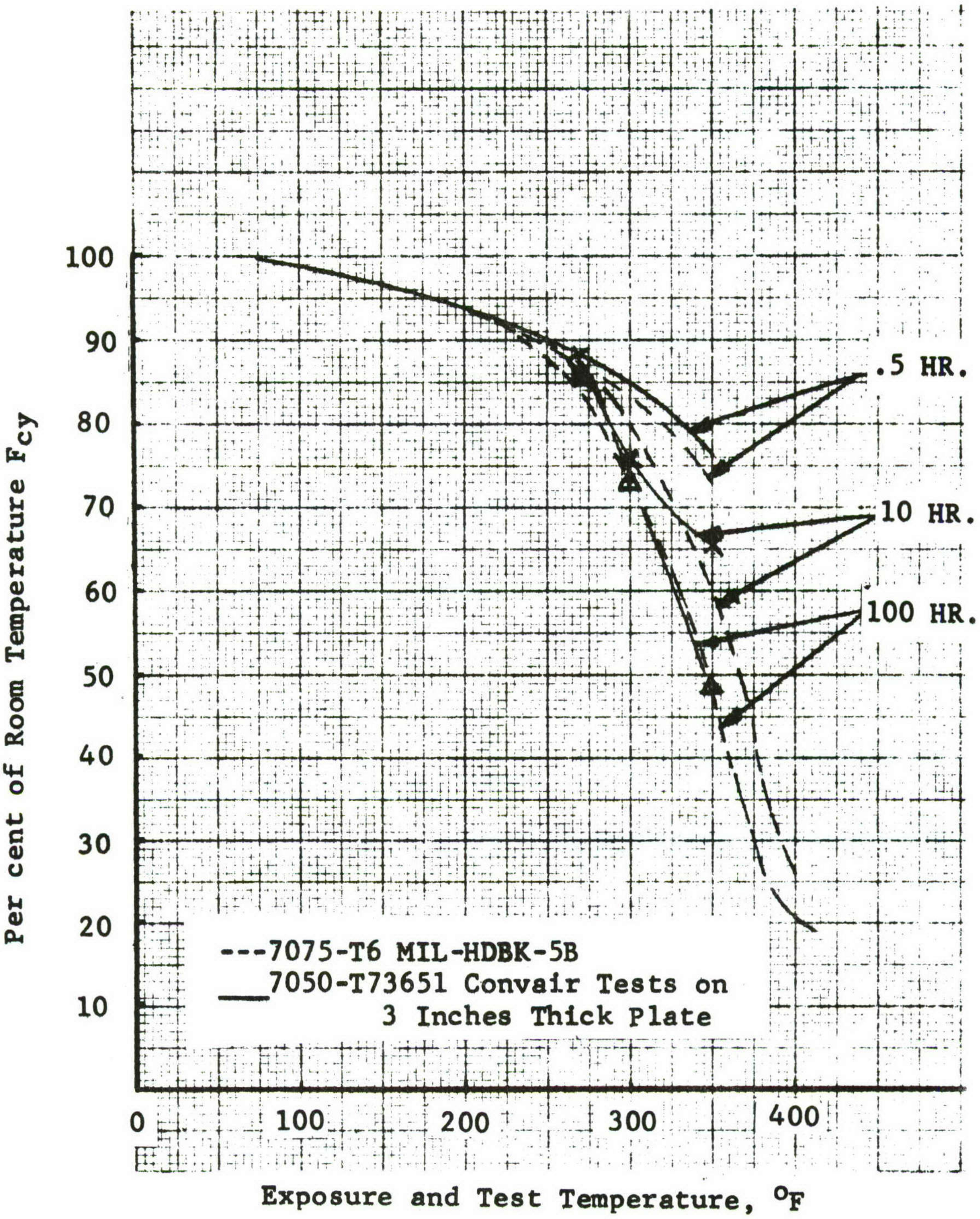


Figure 92 Effect of Elevated Temperature on the Compression Yield Strength of 7050-T73651 Plate at Temperature

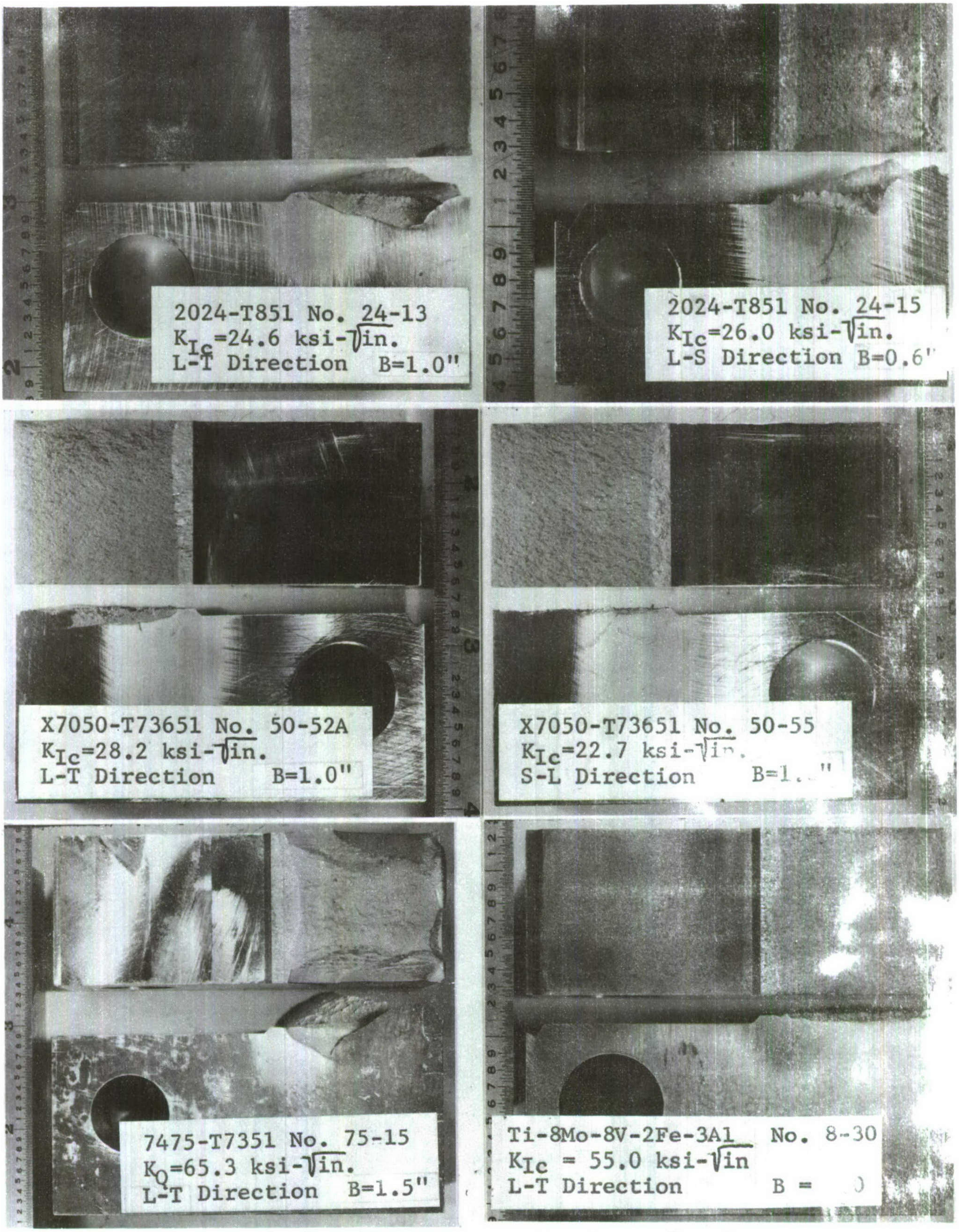


Figure 93 Typical Failed Fracture Toughness Specimens

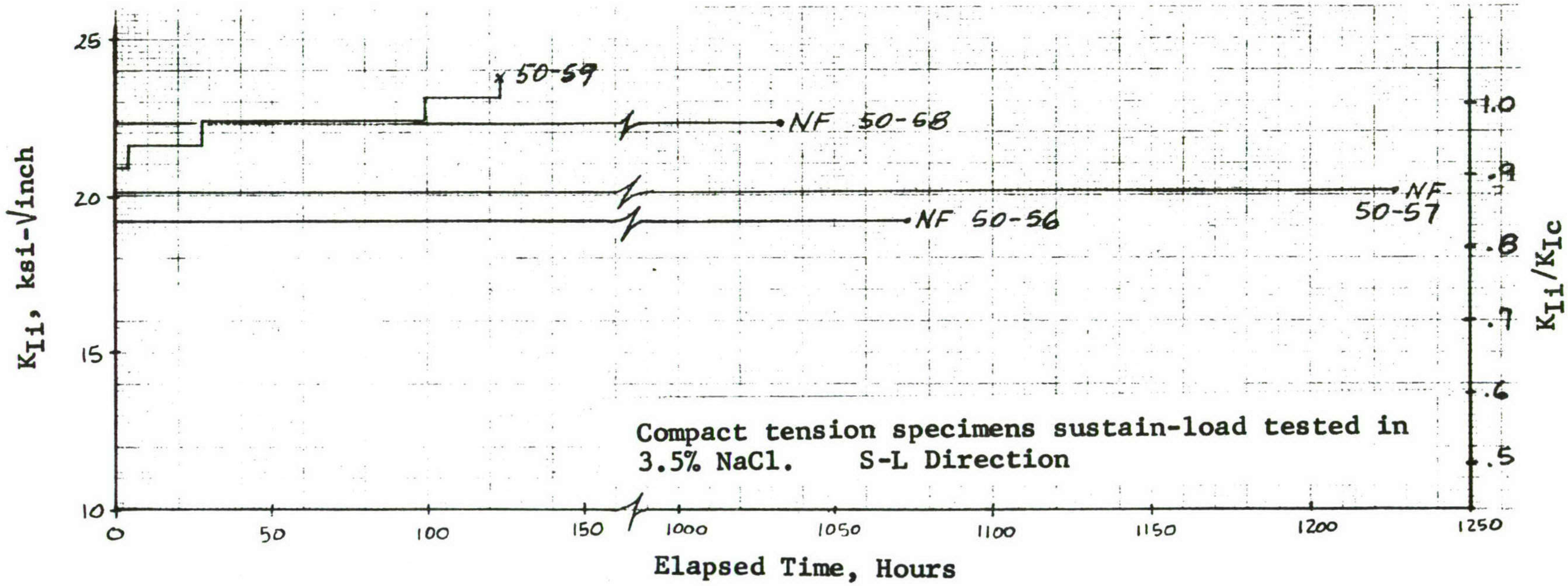


Figure 94 Stress Corrosion Tests on 7050-T73651 Plate, 3" Thick

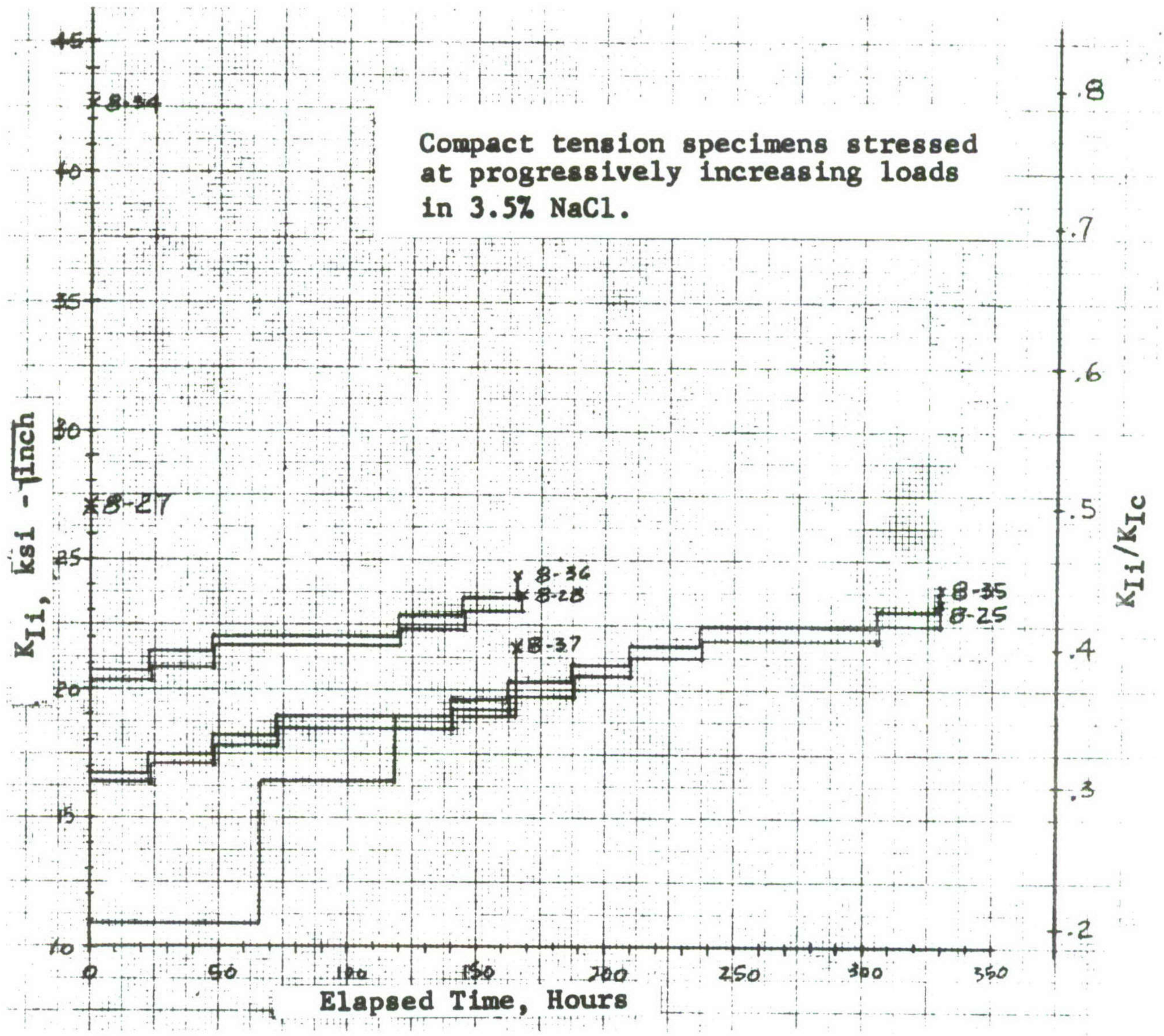


Figure 95 Stress Corrosion Tests on Ti-8Mo-8V-2Fe-3Al STA, 1" Thick Plate

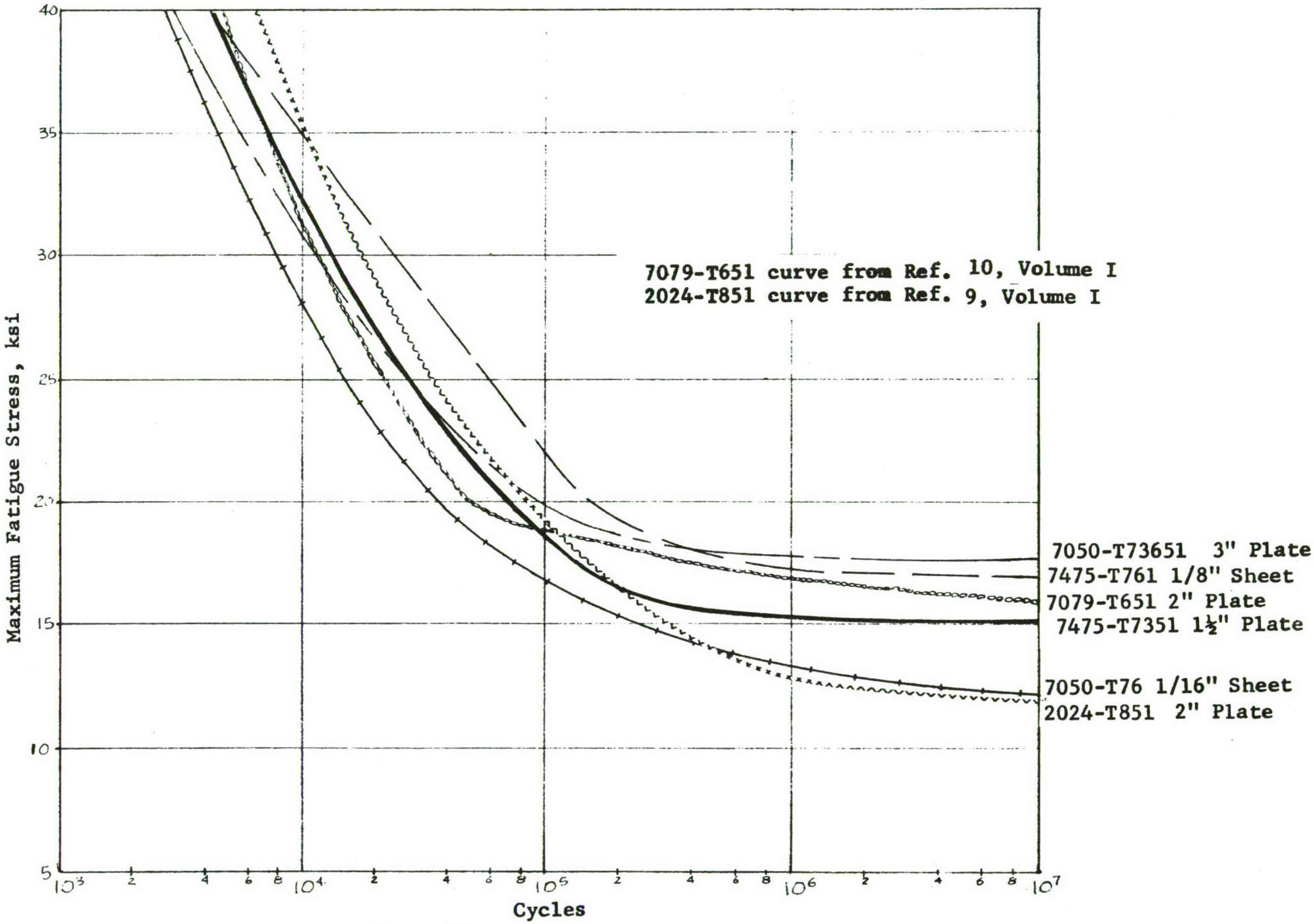


Figure 96 Comparison of Notched Axial Fatigue Properties of Aluminum Alloys, R = 0.1, K_t =3

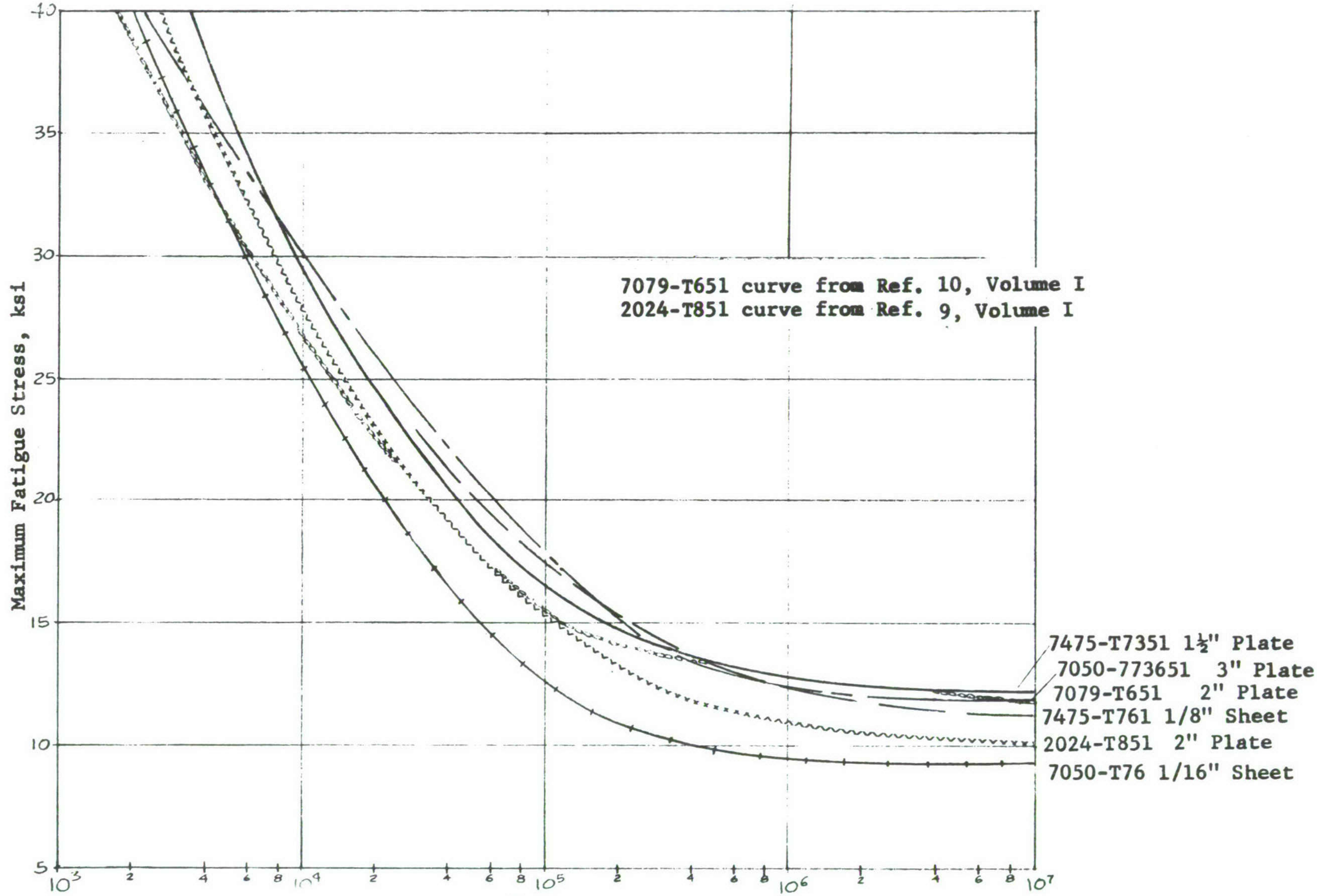


Figure 97 Comparison of Notched Axial Fatigue Properties of Aluminum Alloys, $R = 0.1$, $K_t = 5$

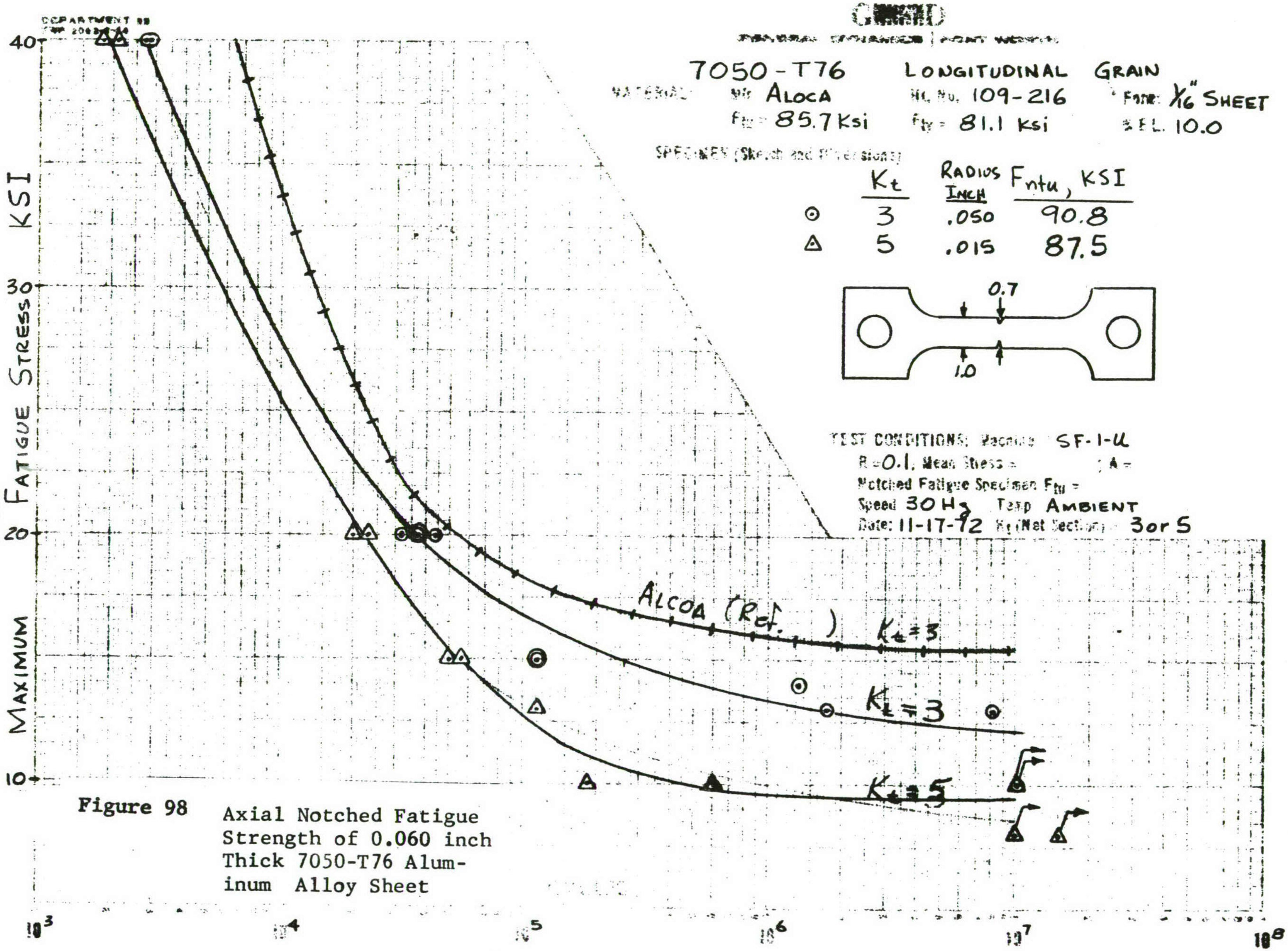


Figure 98 Axial Notched Fatigue Strength of 0.060 inch Thick 7050-T76 Aluminum Alloy Sheet

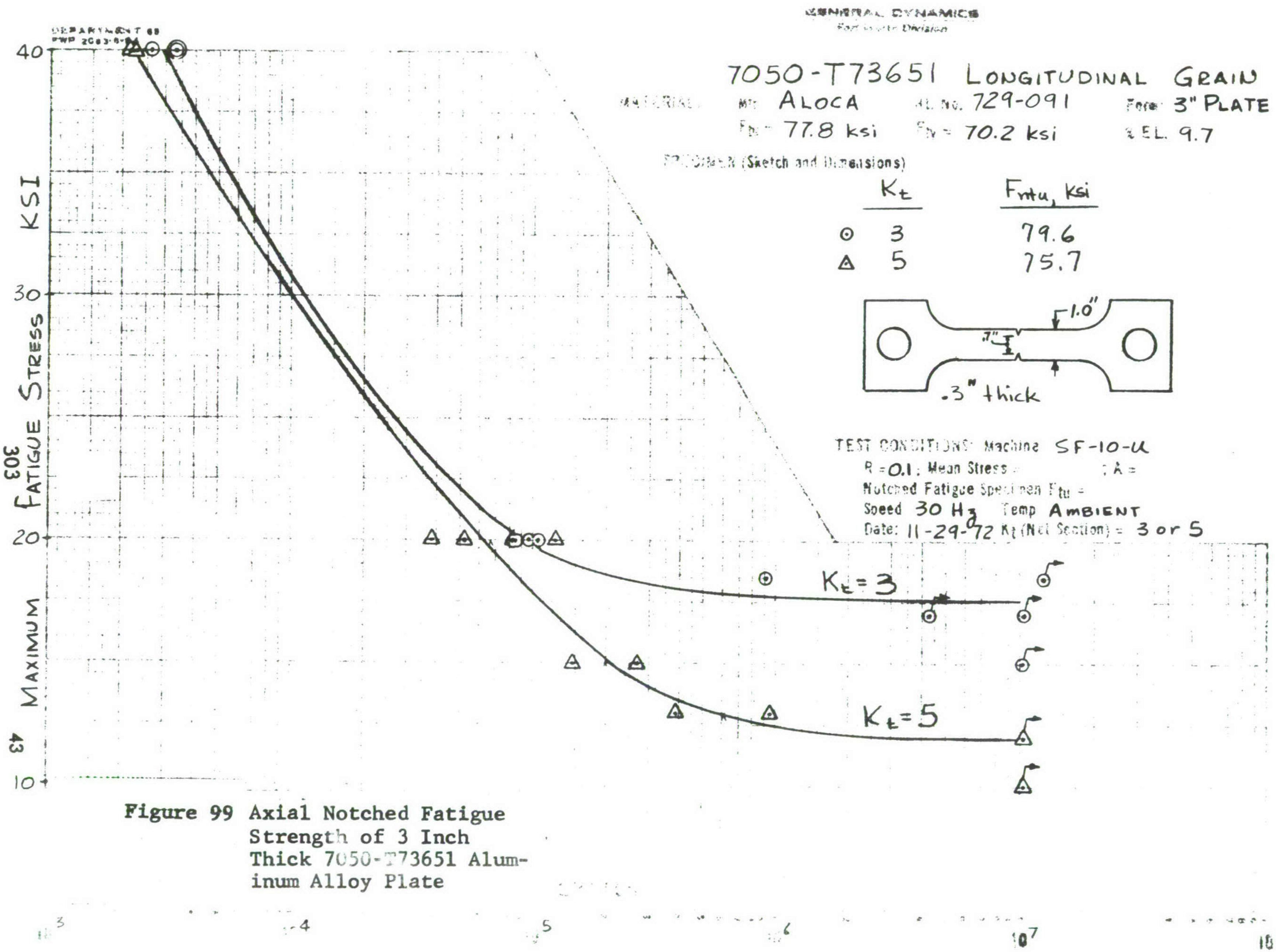


Figure 99 Axial Notched Fatigue Strength of 3 Inch Thick 7050-T73651 Aluminum Alloy Plate

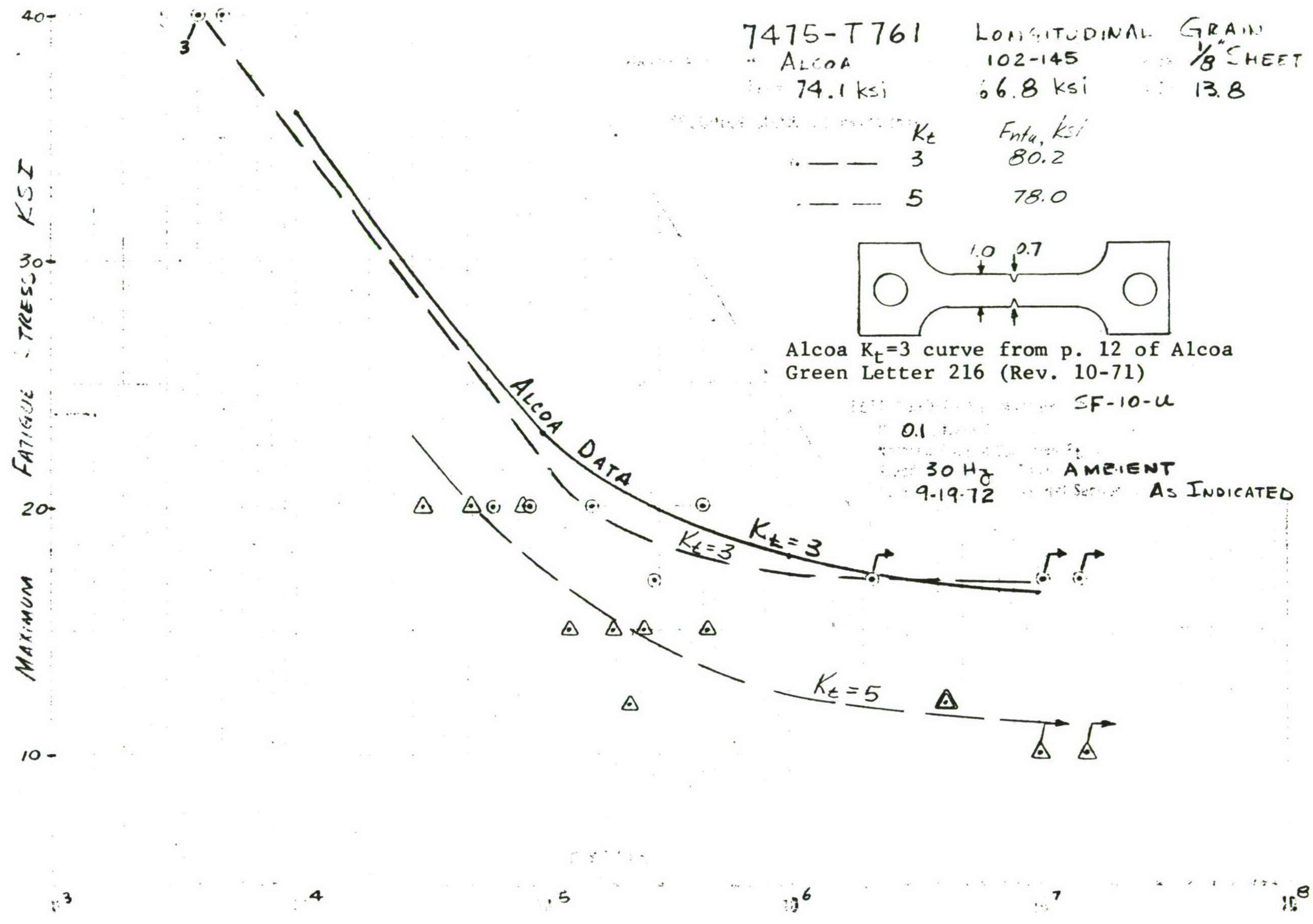


Figure 100 Axial Notched Fatigue Strength of 0.125 inch Thick 7475-T761 Aluminum Alloy Sheet

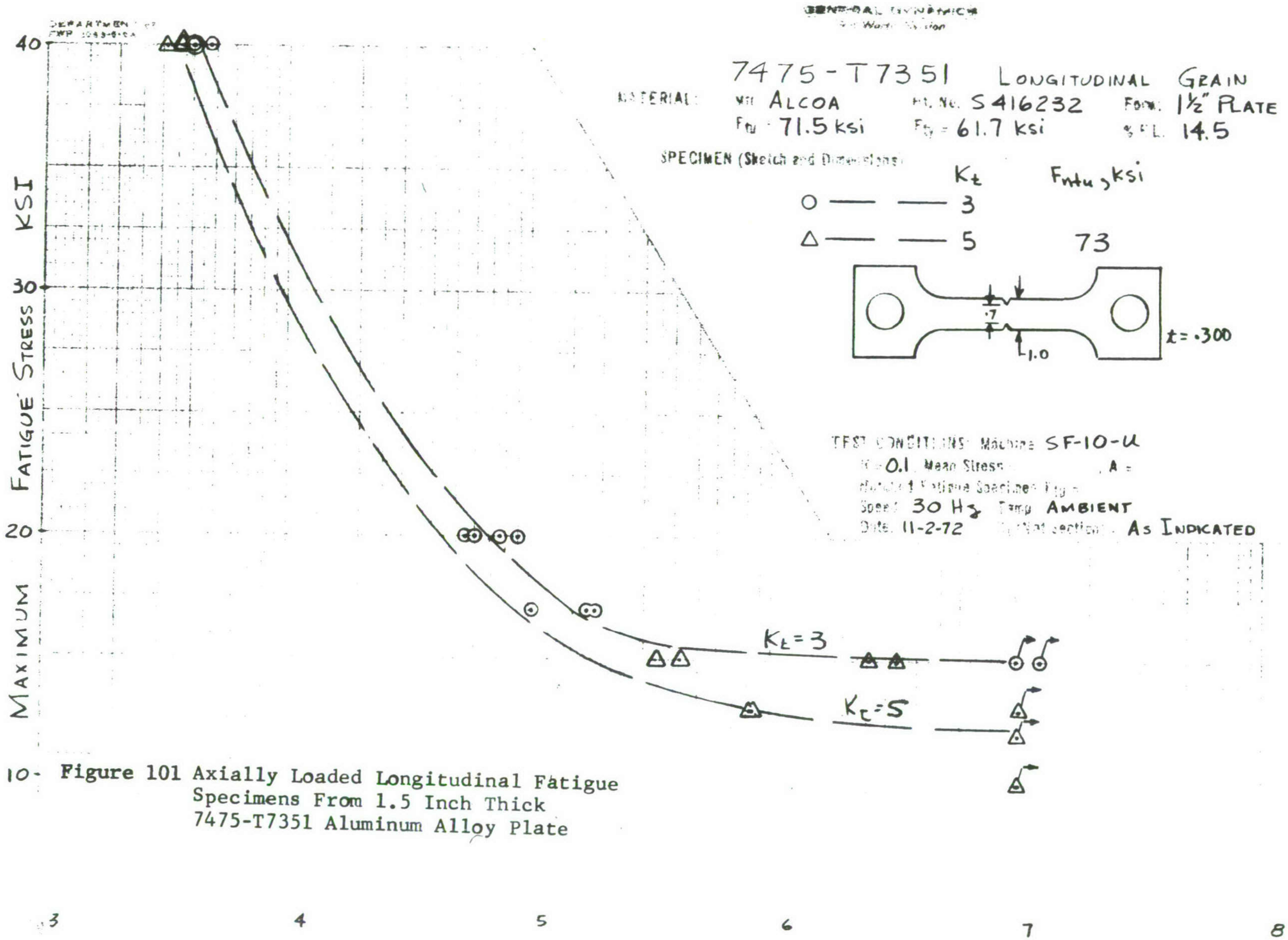


Figure 101 Axially Loaded Longitudinal Fatigue Specimens From 1.5 Inch Thick 7475-T7351 Aluminum Alloy Plate

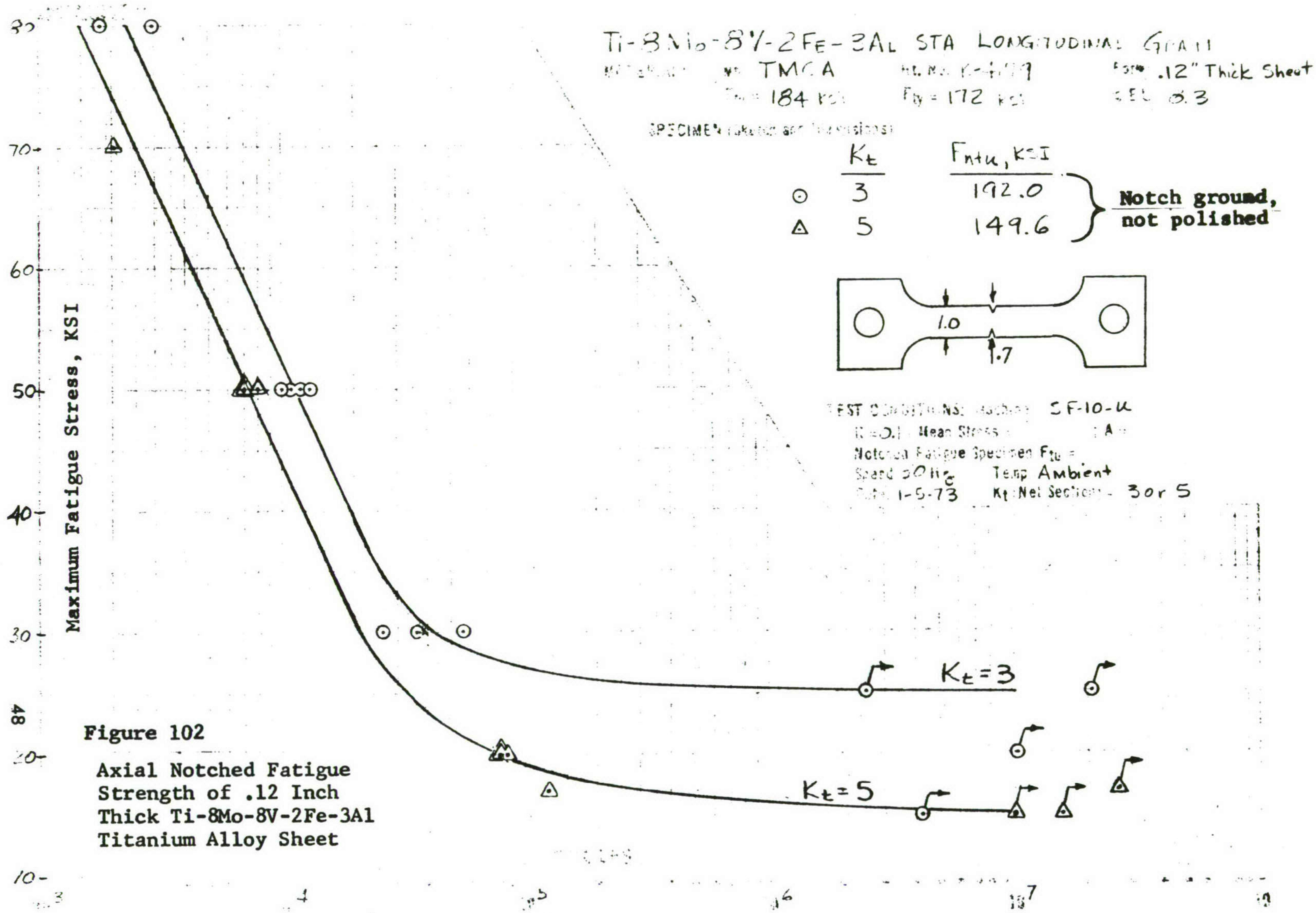


Figure 102

Axial Notched Fatigue Strength of .12 Inch Thick Ti-8Mo-8V-2Fe-3Al Titanium Alloy Sheet

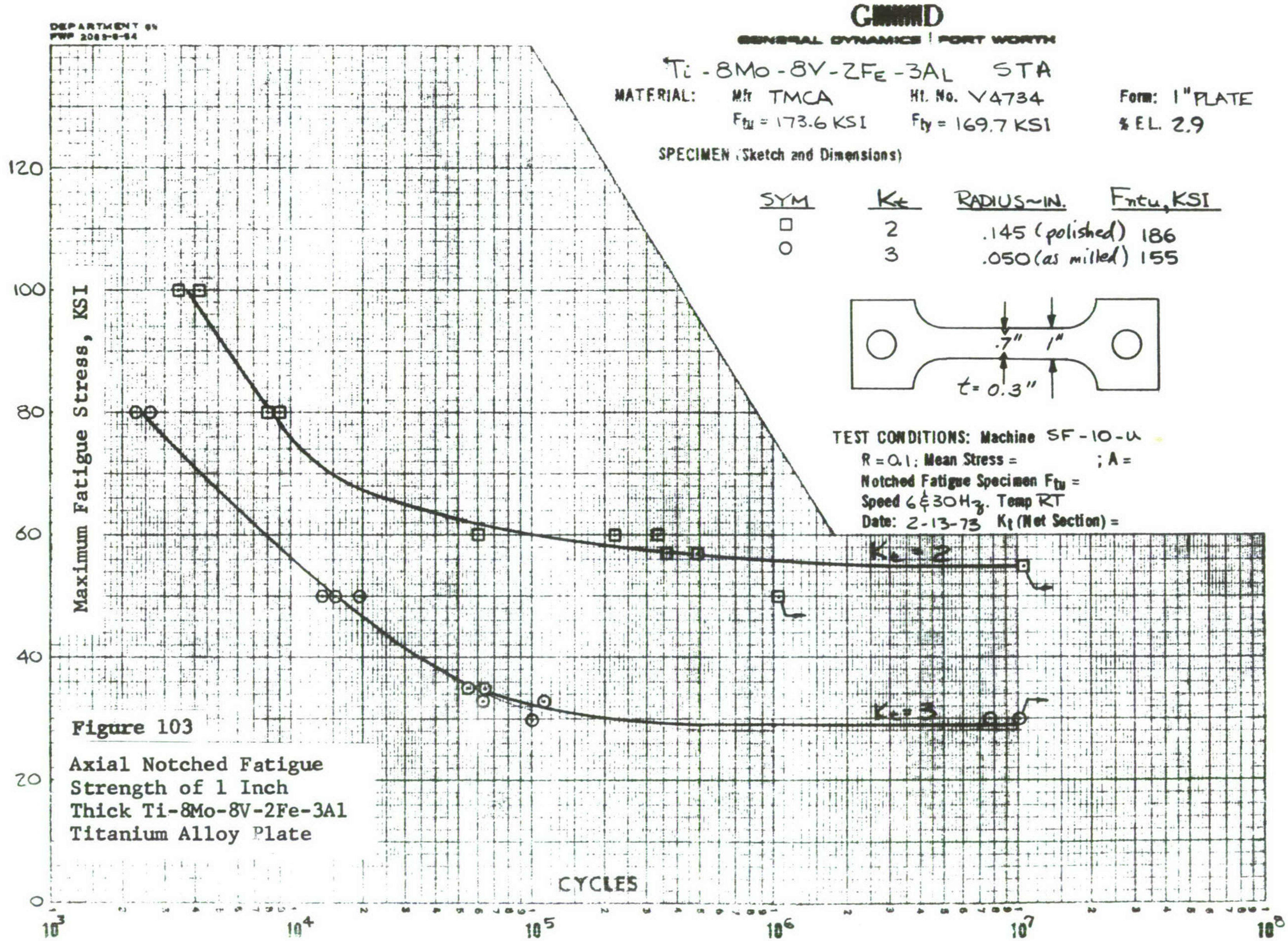
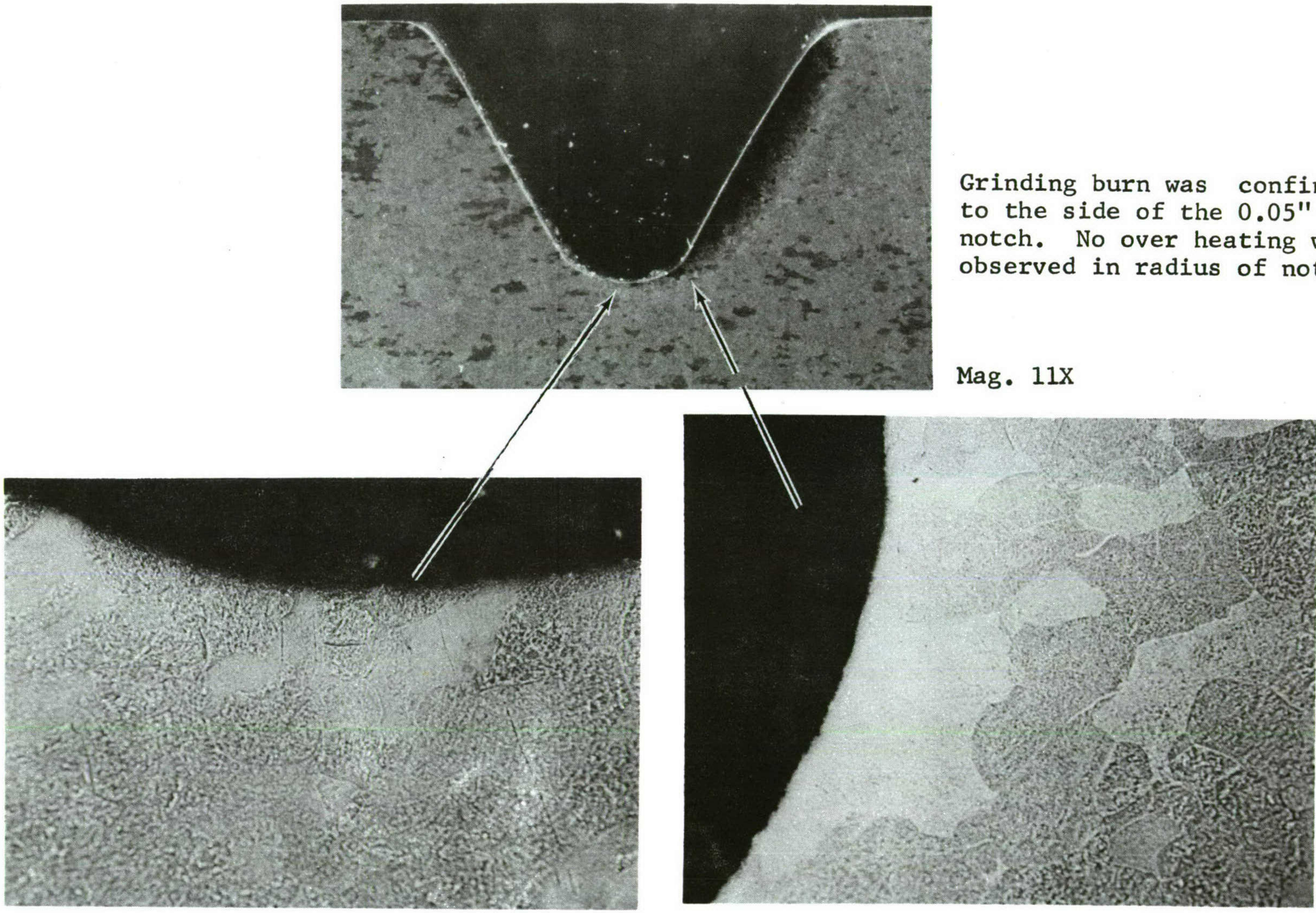


Figure 103

Axial Notched Fatigue Strength of 1 Inch Thick Ti-8Mo-8V-2Fe-3Al Titanium Alloy Plate



Grinding burn was confined to the side of the 0.05" radius notch. No over heating was observed in radius of notch.

Mag. 11X

Mag. 200X Etch: 2% HF-20% HNO_3

Figure 104 Grinding Burn on Side of Notch in Ti-8Mo-8V-2Fe-3Al Fatigue Specimen 8-3

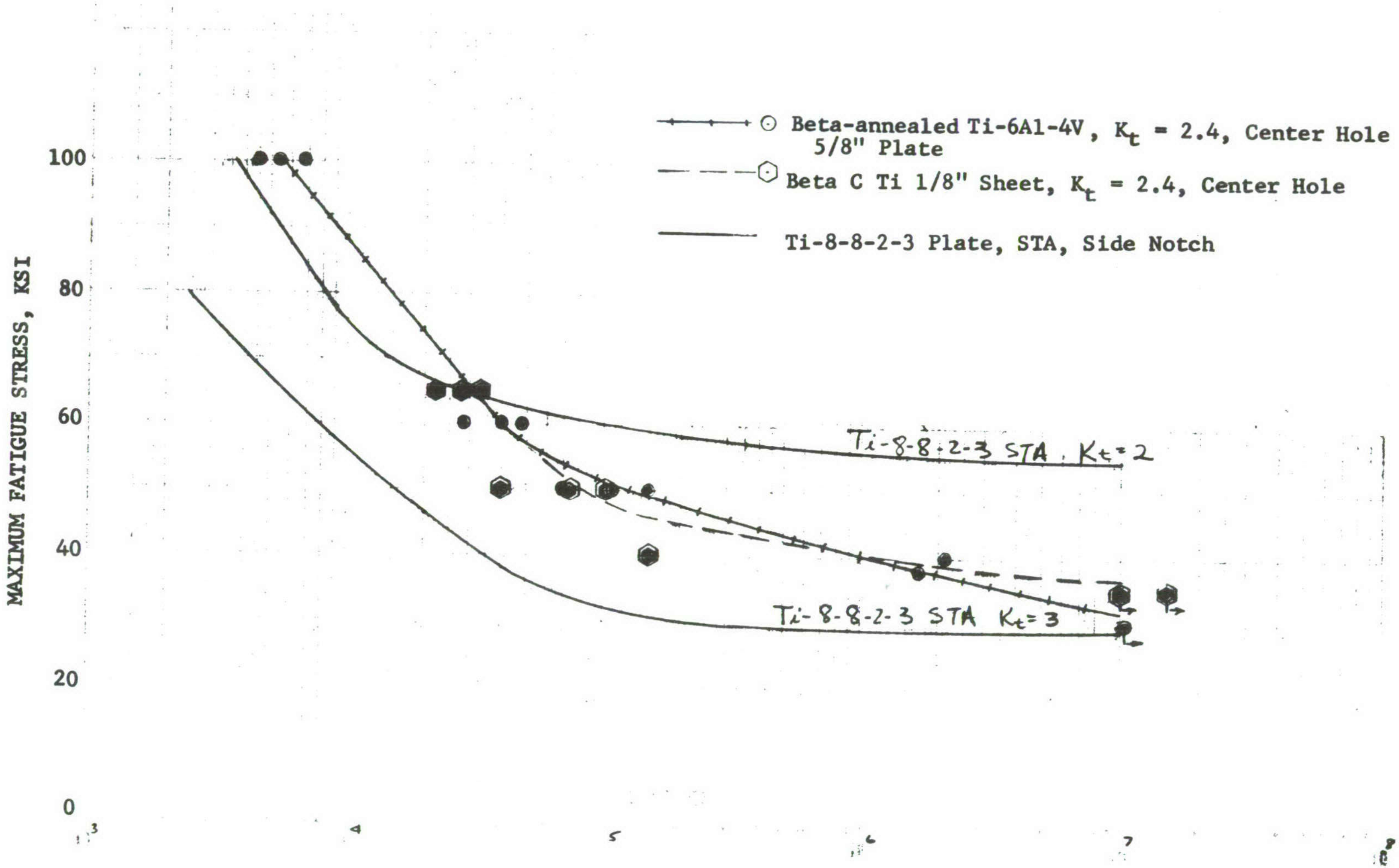


Figure 105 Comparison of Notched Fatigue Strength of Titanium Alloys, R = 0.1

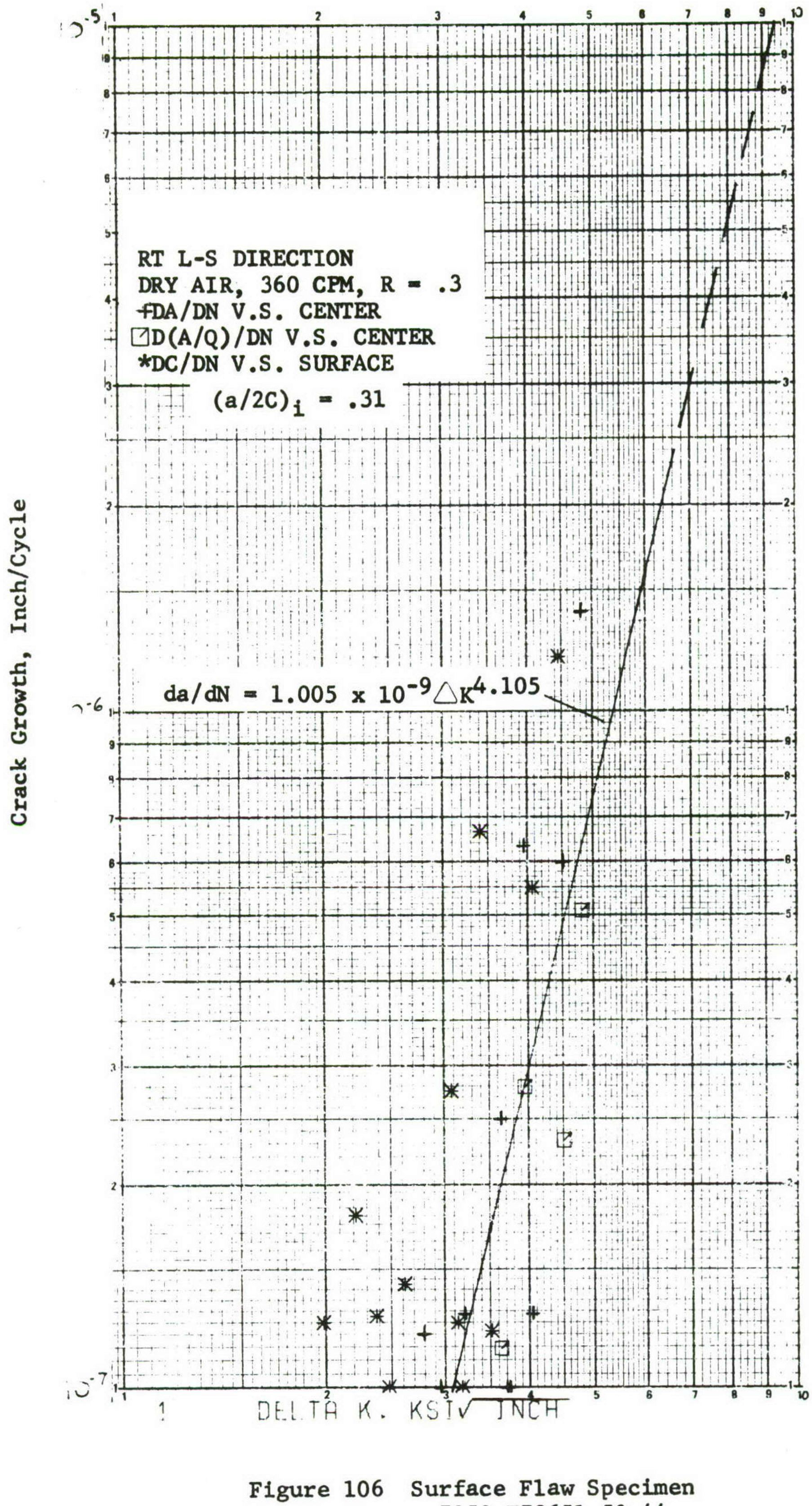


Figure 106 Surface Flaw Specimen
7050-T73651 50-44

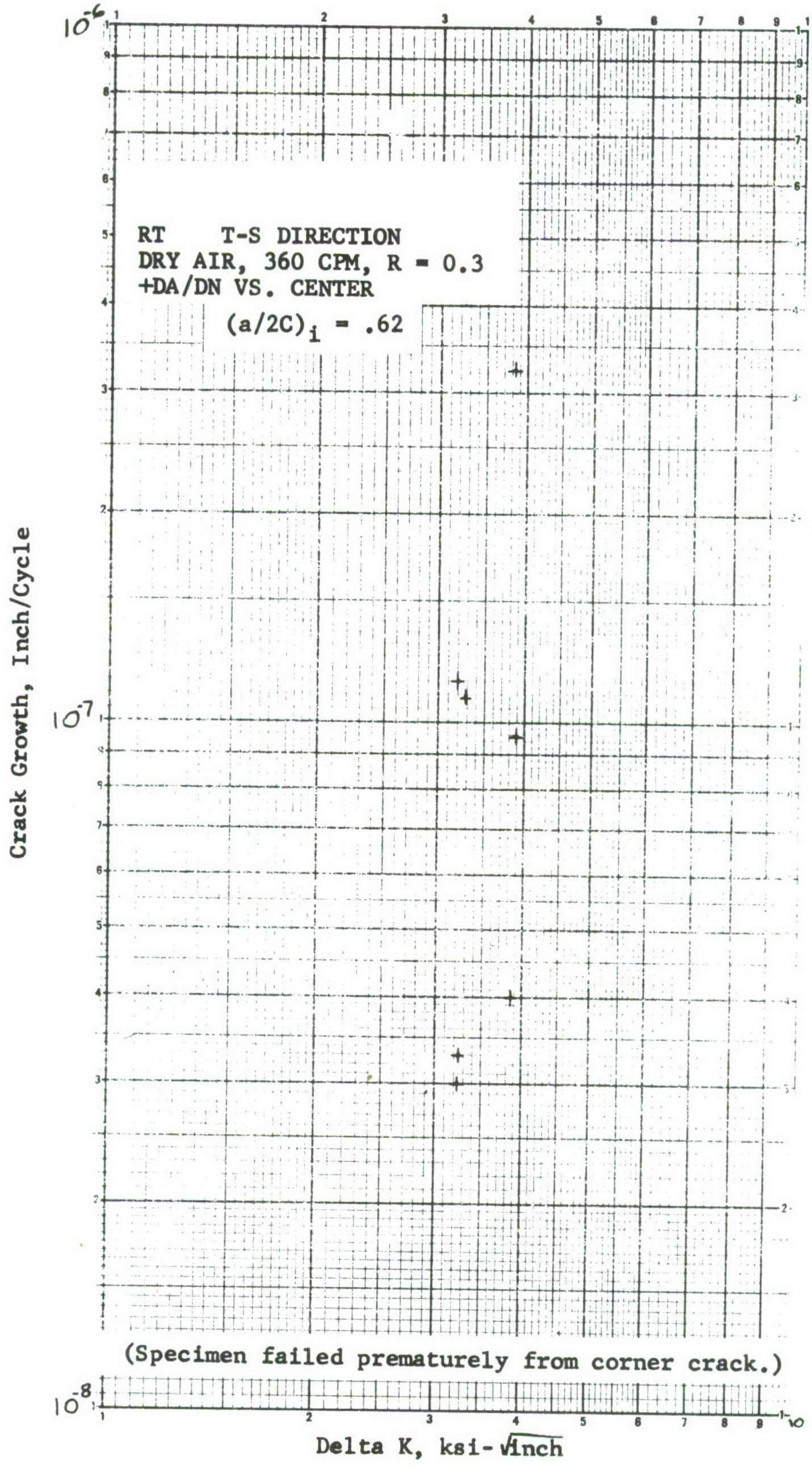


Figure 107 Surface Flaw Specimen
7050-T73651, #50-49

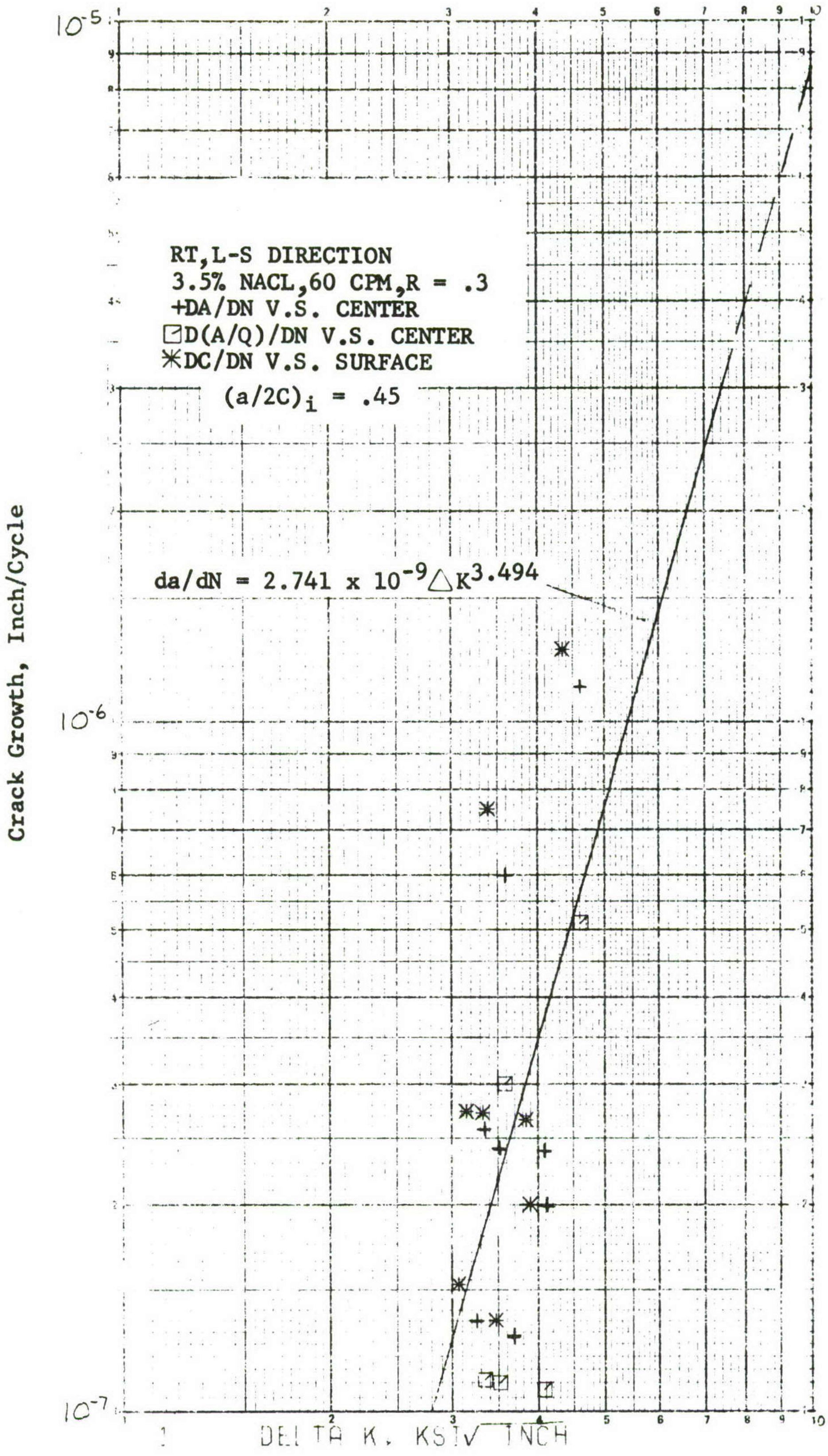


Figure 108 Surface Flaw Specimen
7050-T73651, 50-45

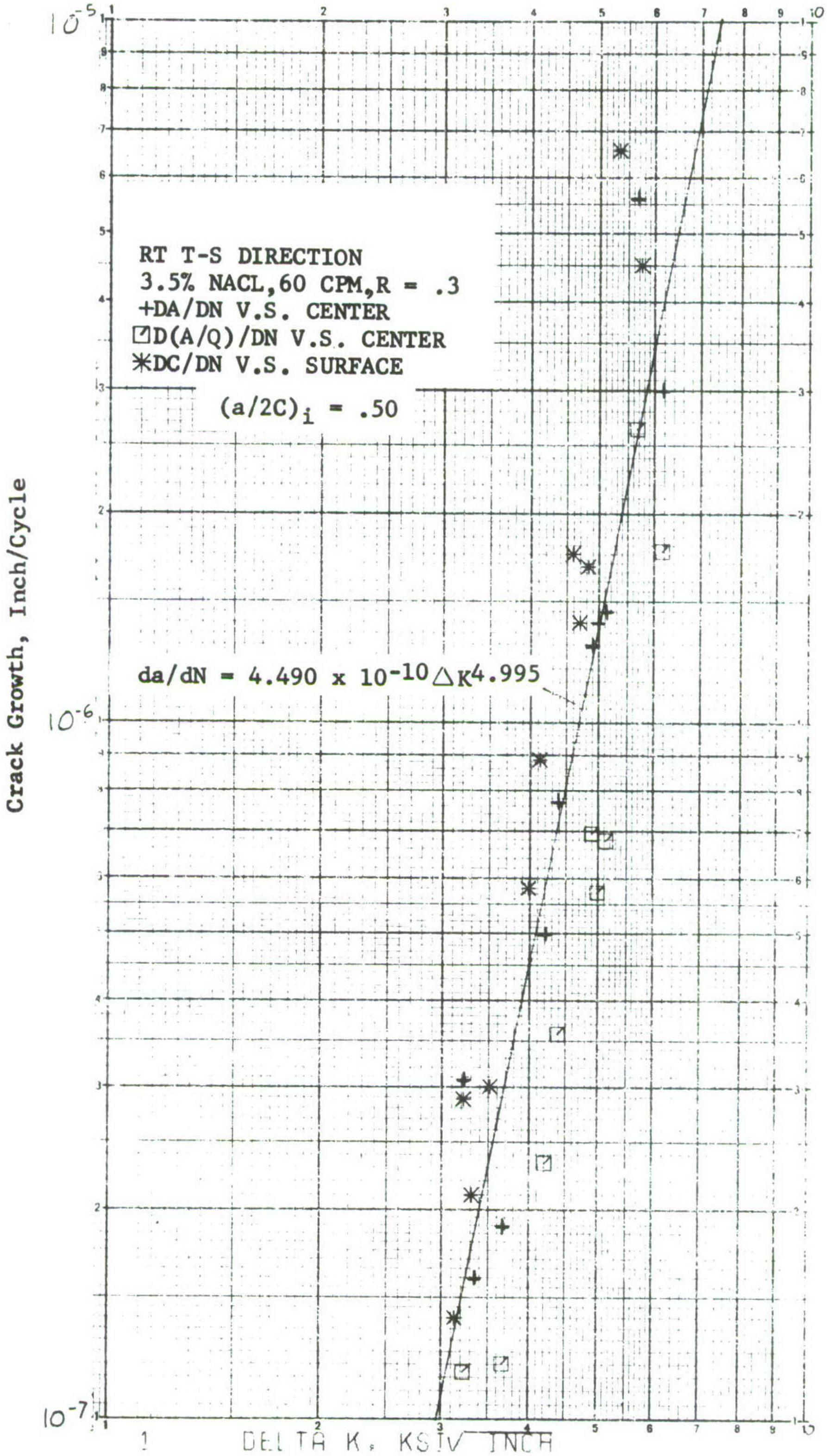


Figure 109 Surface Flaw Specimen
7050-T73651, 50-50

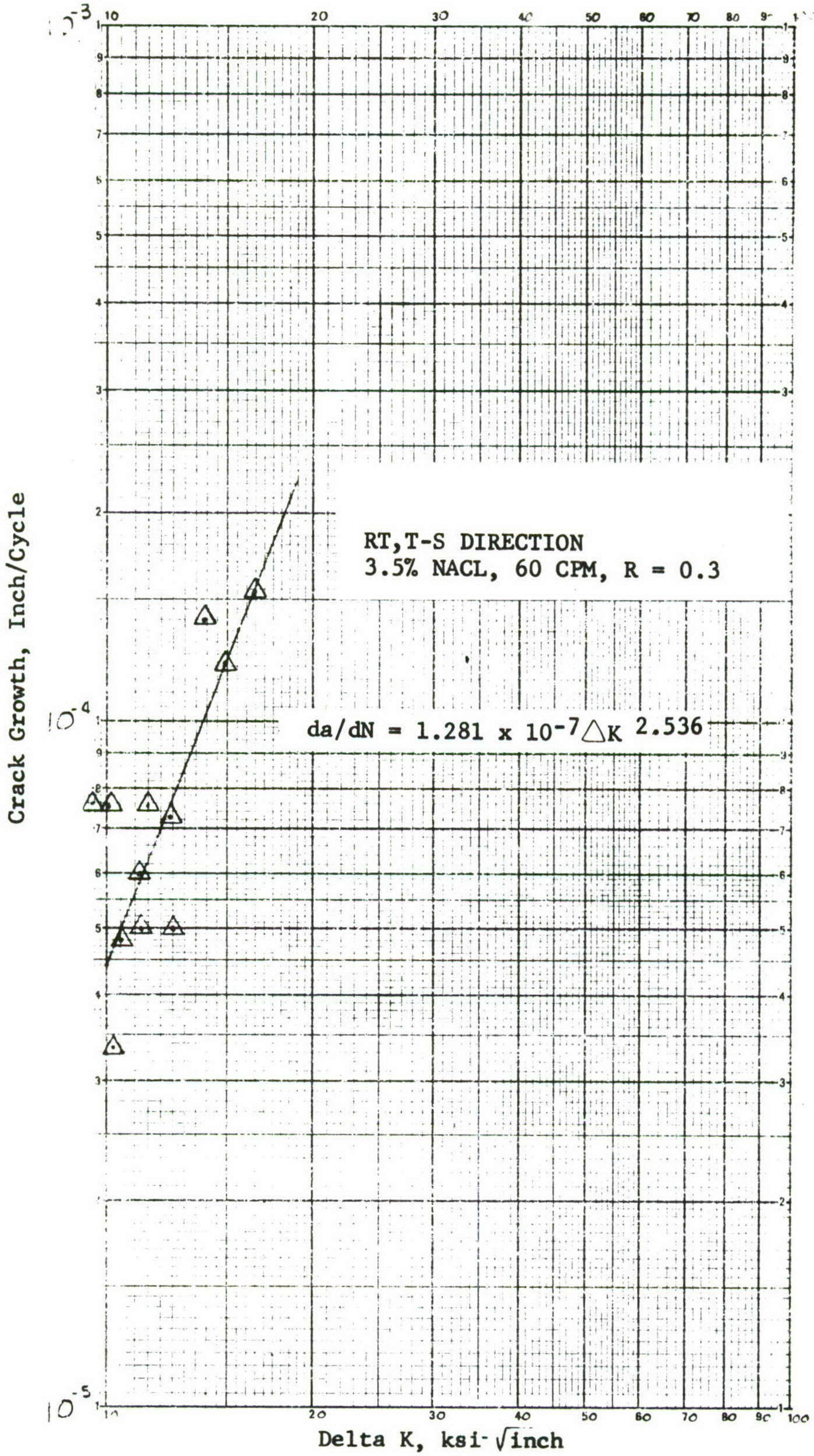


Figure 110 Center Crack Tension Specimen 7050-T73651 #50-50

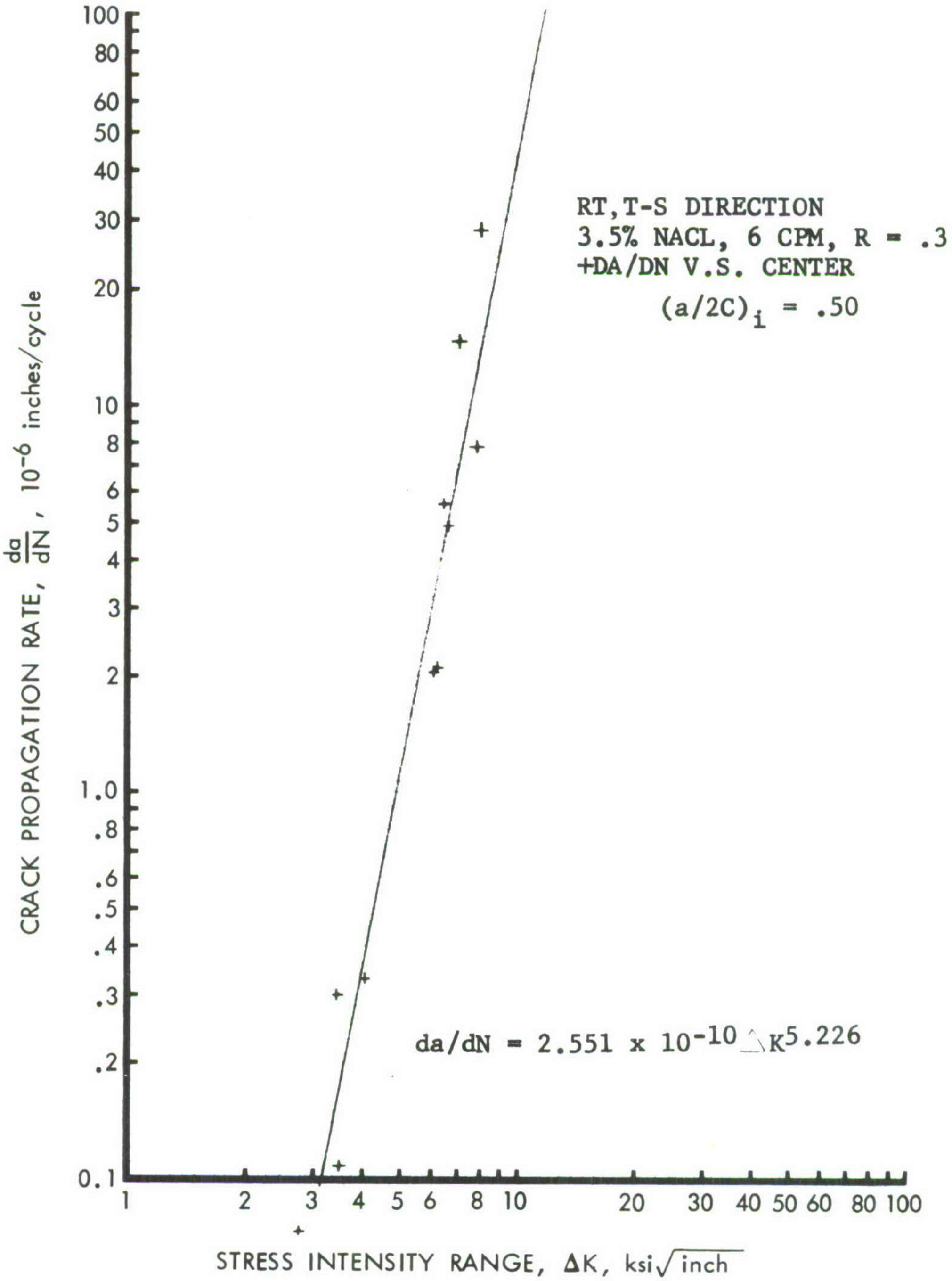


Figure 111 **Surface Flaw Specimen** 7050-T73651 50-51

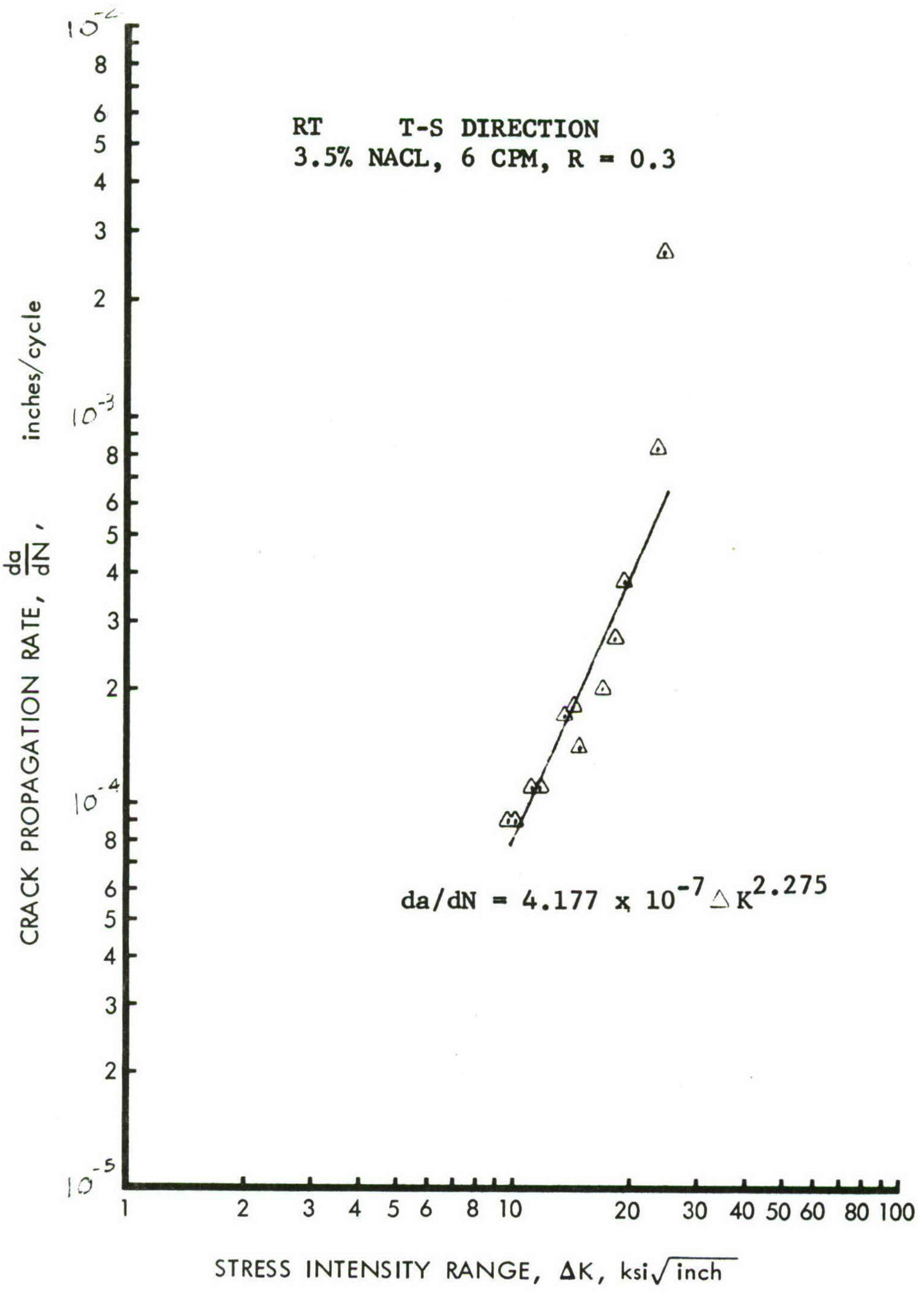


Figure 112 Center Crack Tension Specimen 7050-T73651 #50-51

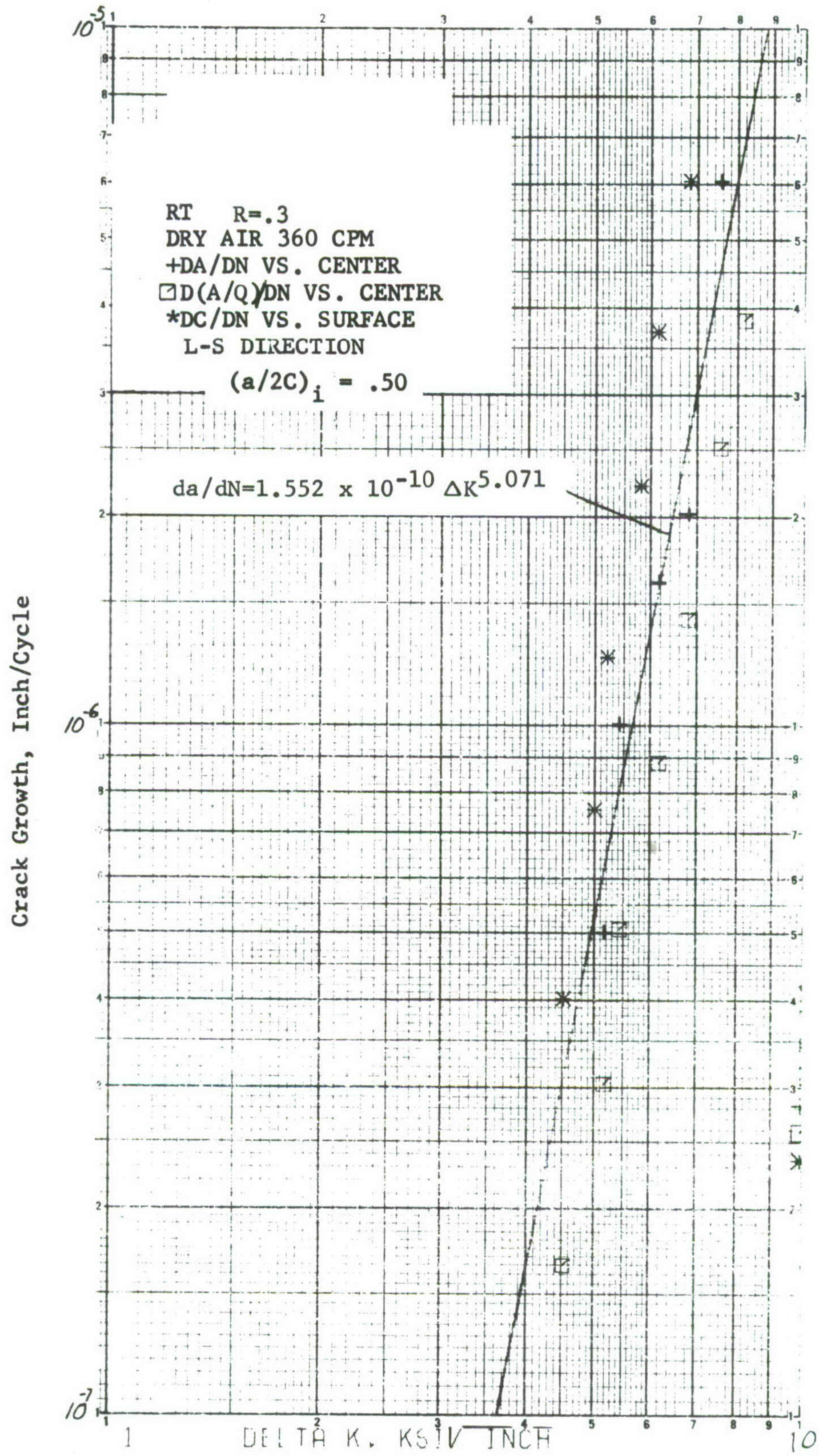


Figure 113 Surface Flaw Specimen 7475-T7351, #75-23

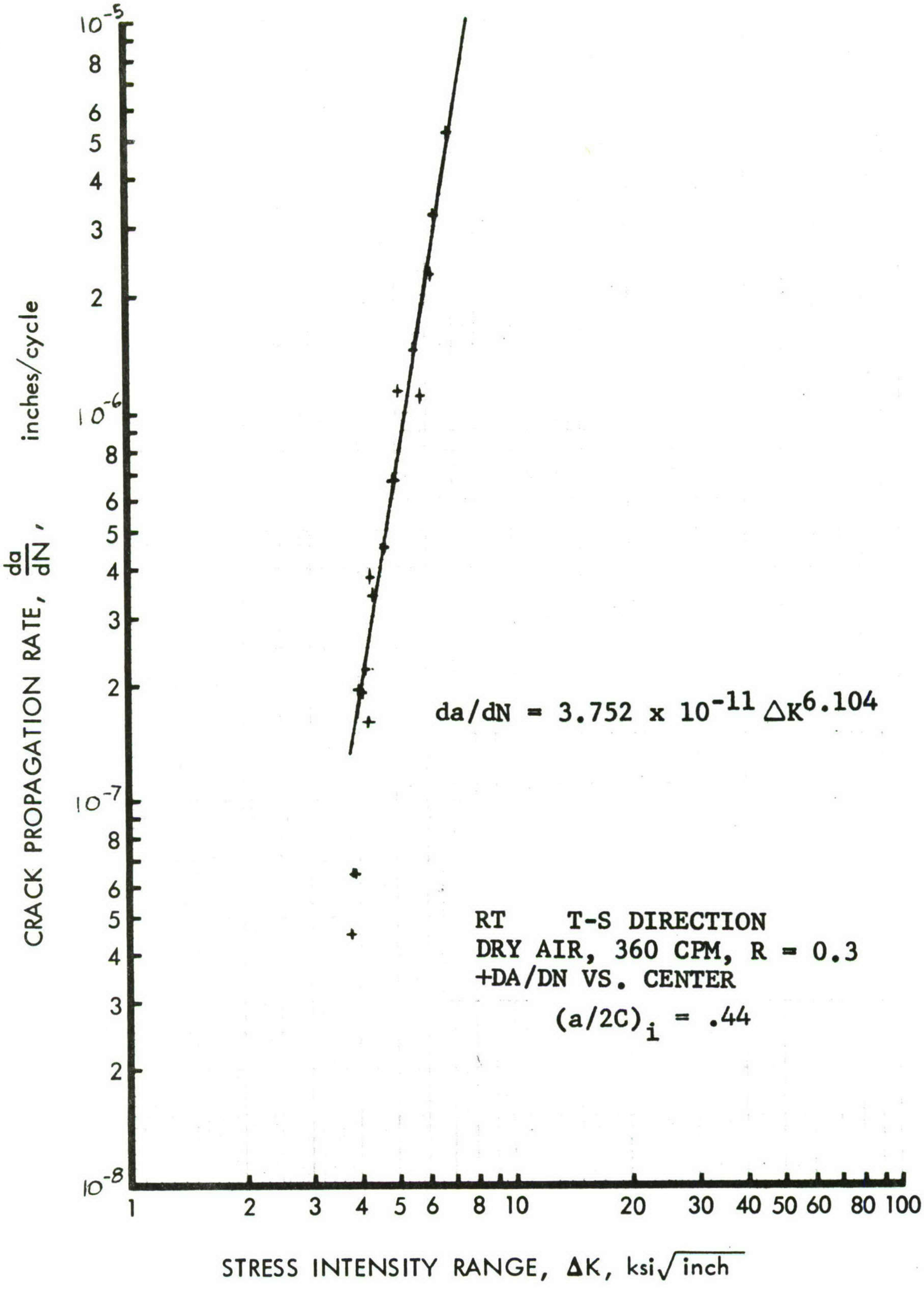


Figure 114 Surface Flaw Specimen 7475-T7351, #75-21

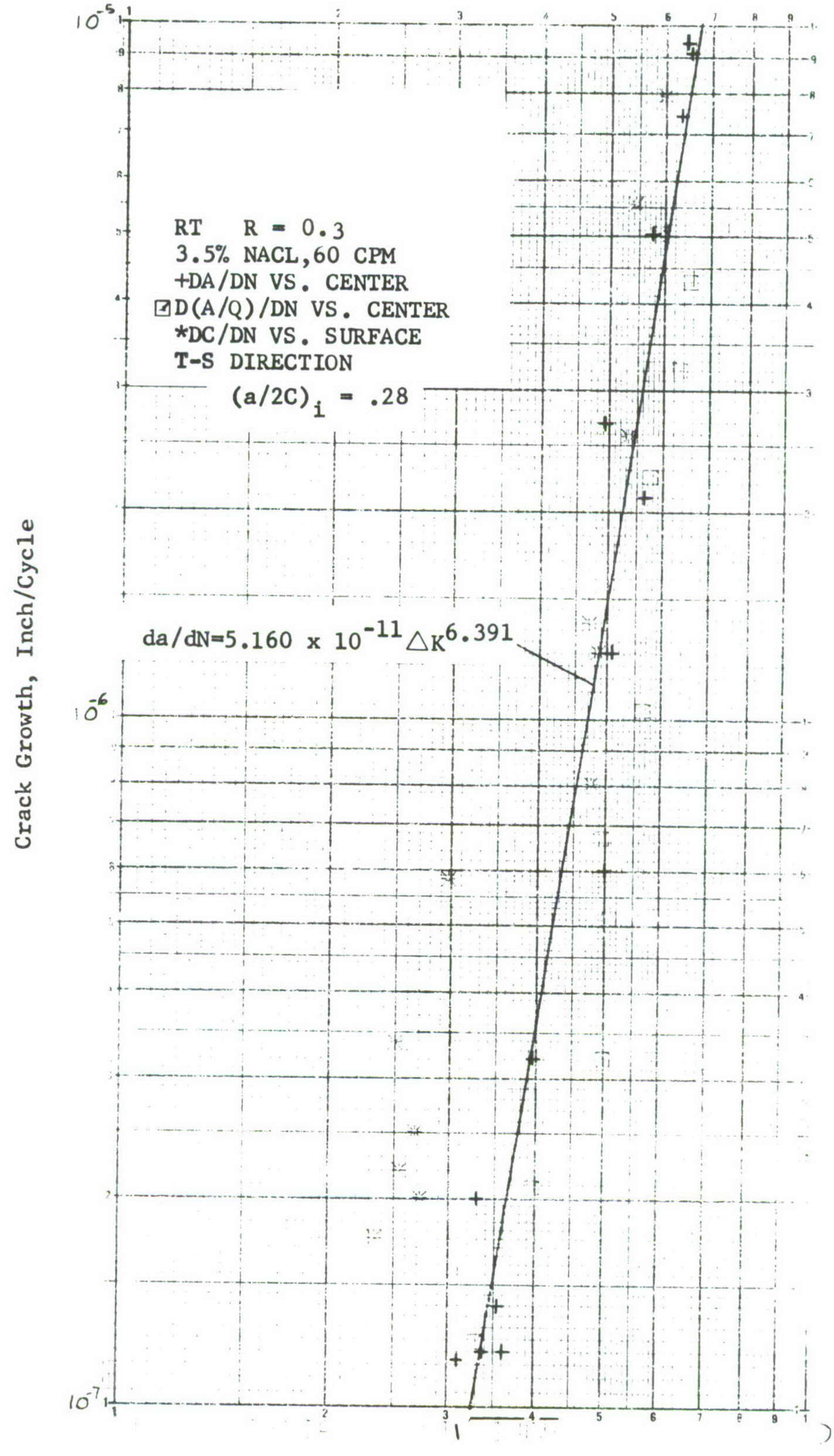


Figure 115 Surface Flaw Specimen 7475-T7351, #75-19

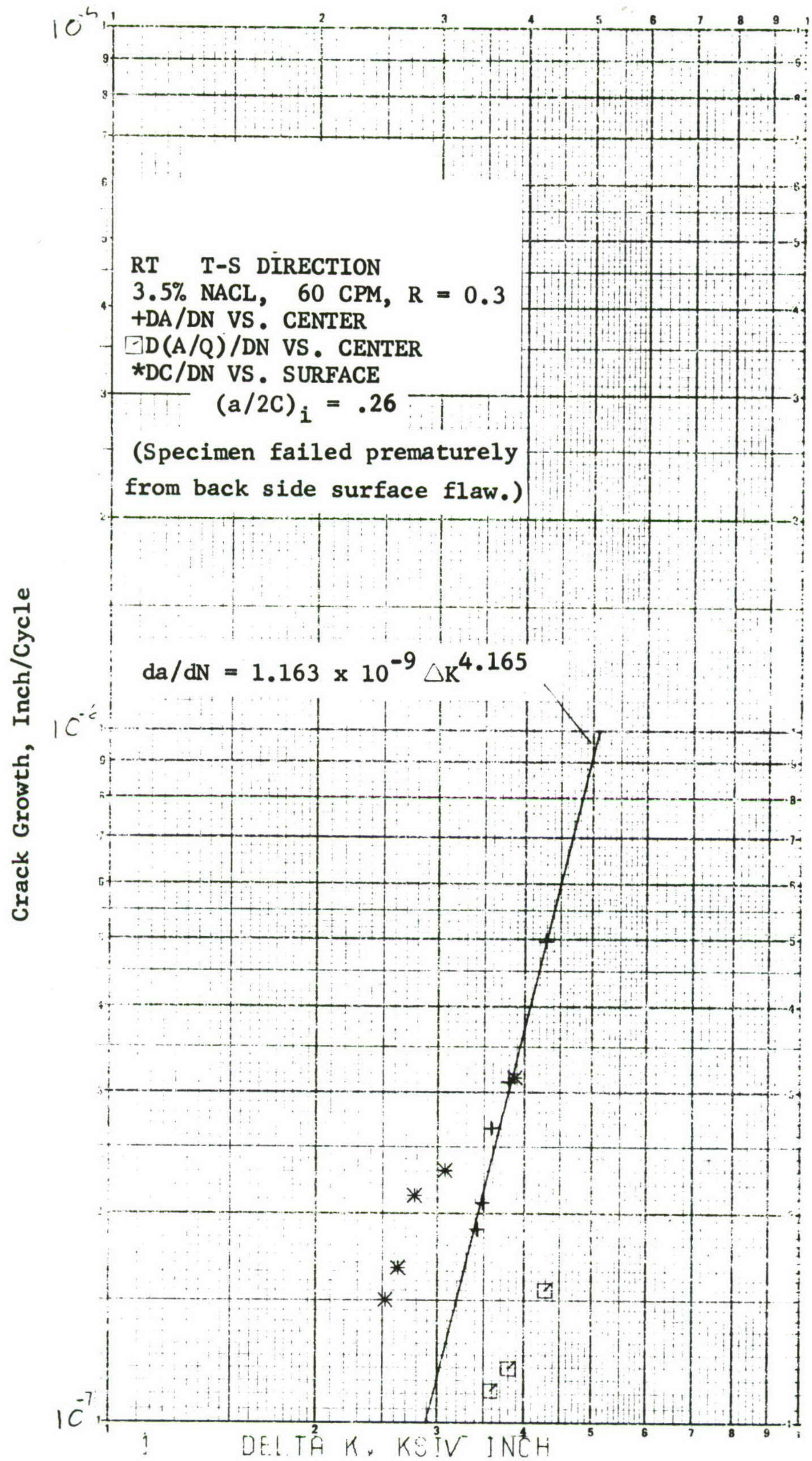


Figure 116 Surface Flaw Specimen 7475-T7351, #75-20

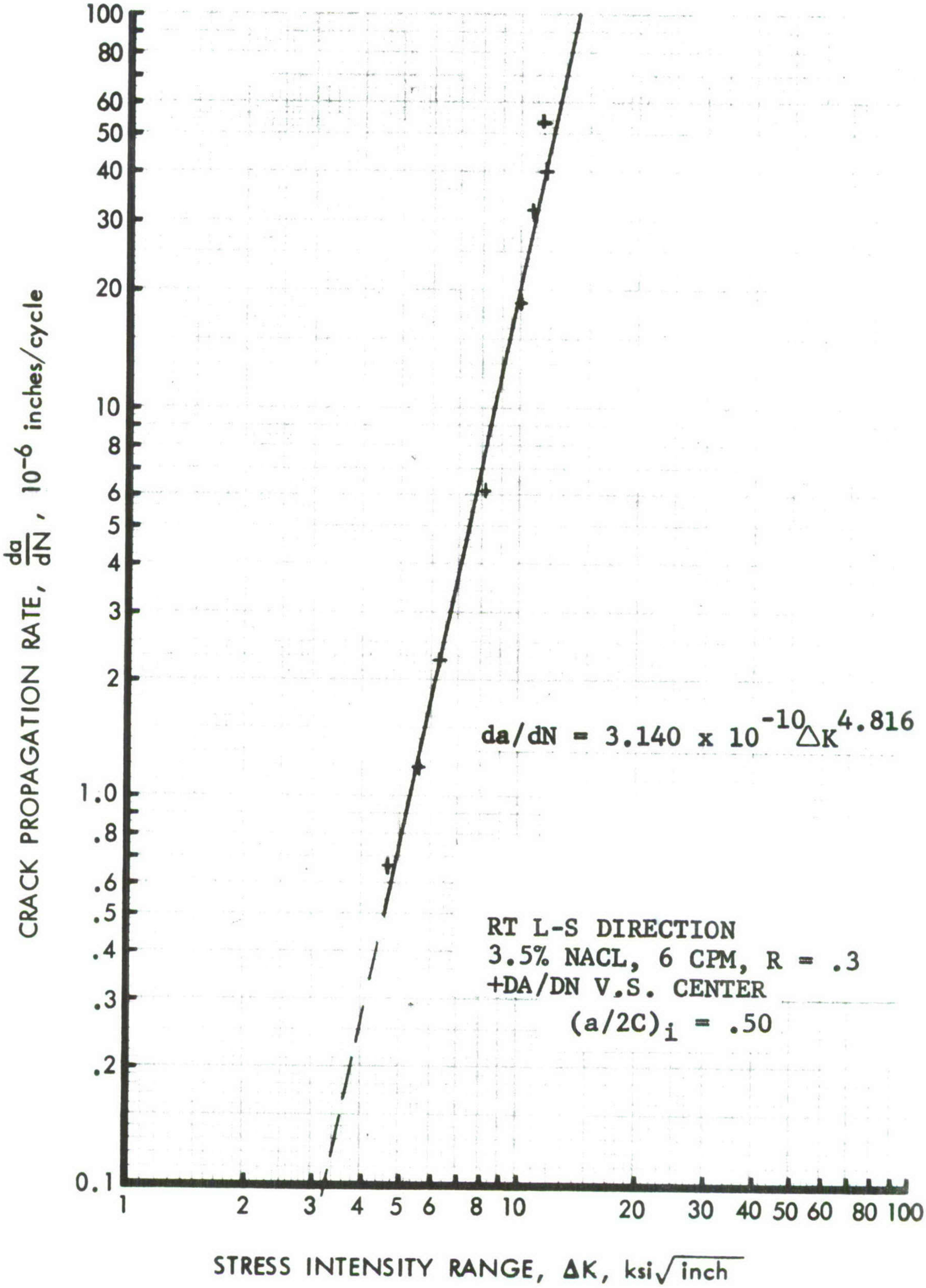


Figure 117 Surface Flaw Specimen 7475-T7351, #75-25

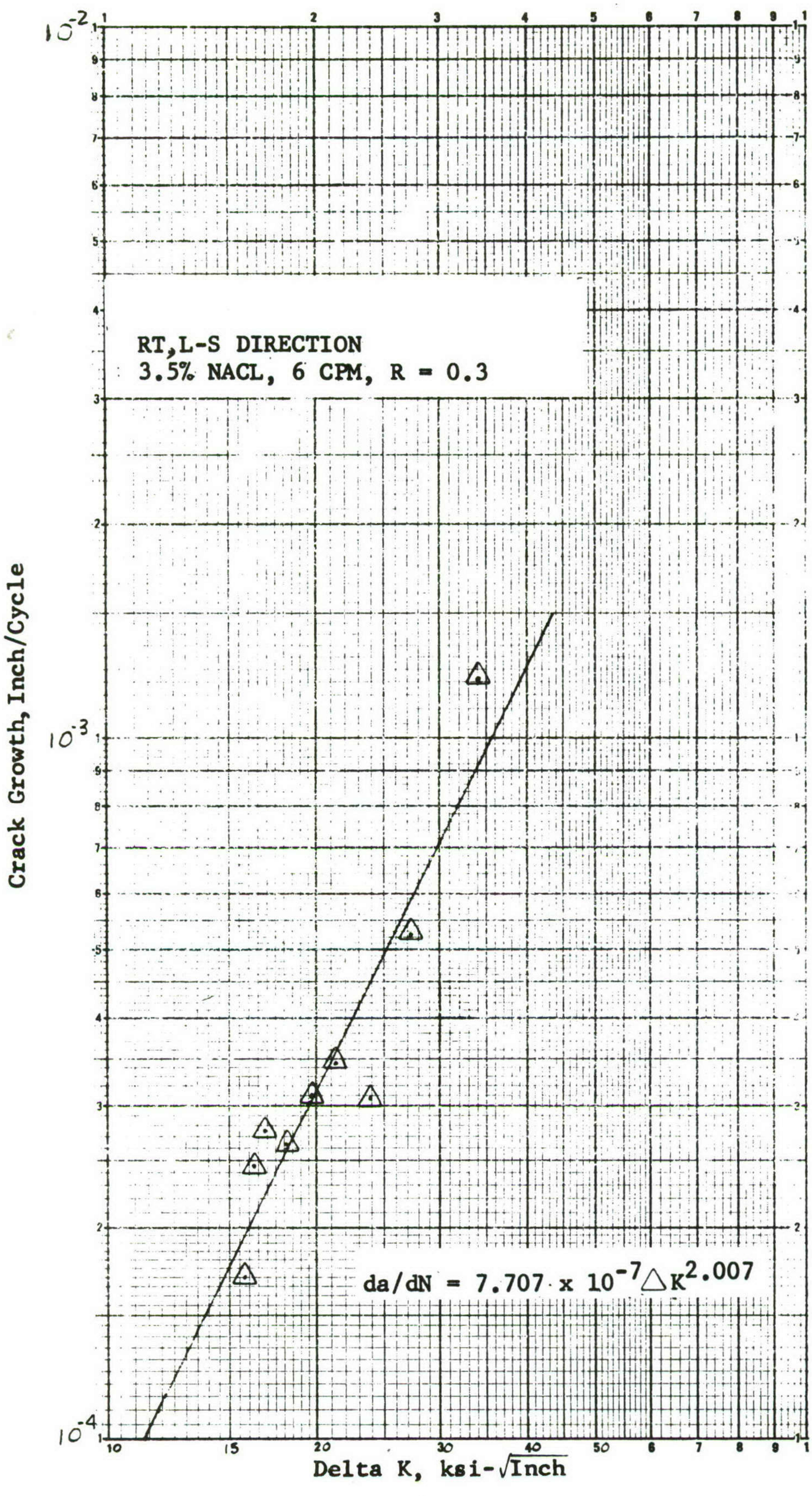


Figure 118 Center Crack Tension Specimen 7475-T7351, #75-25

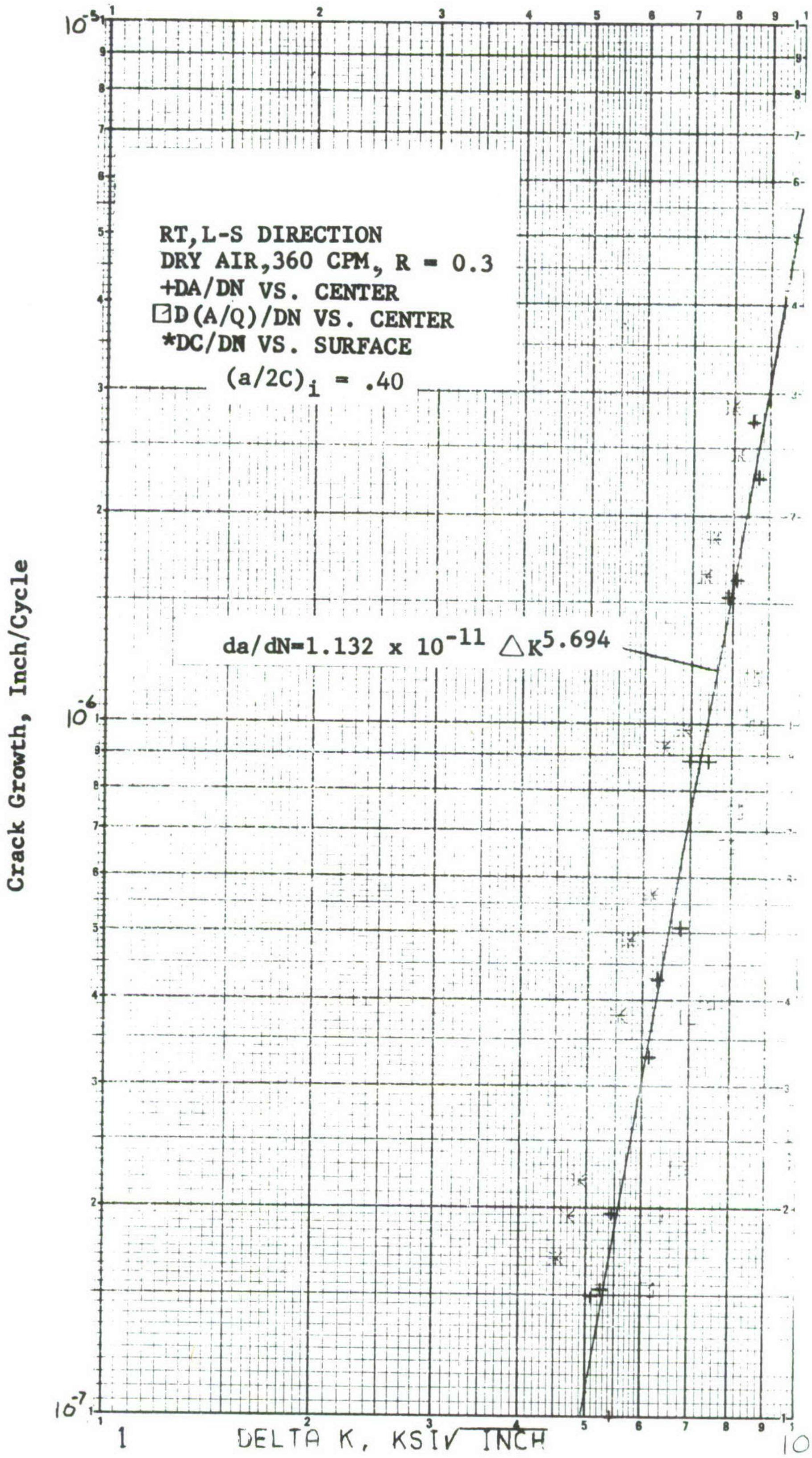


Figure 119 Surface Flaw Specimen TI-8MO-8V-2FE-3AL 8-17

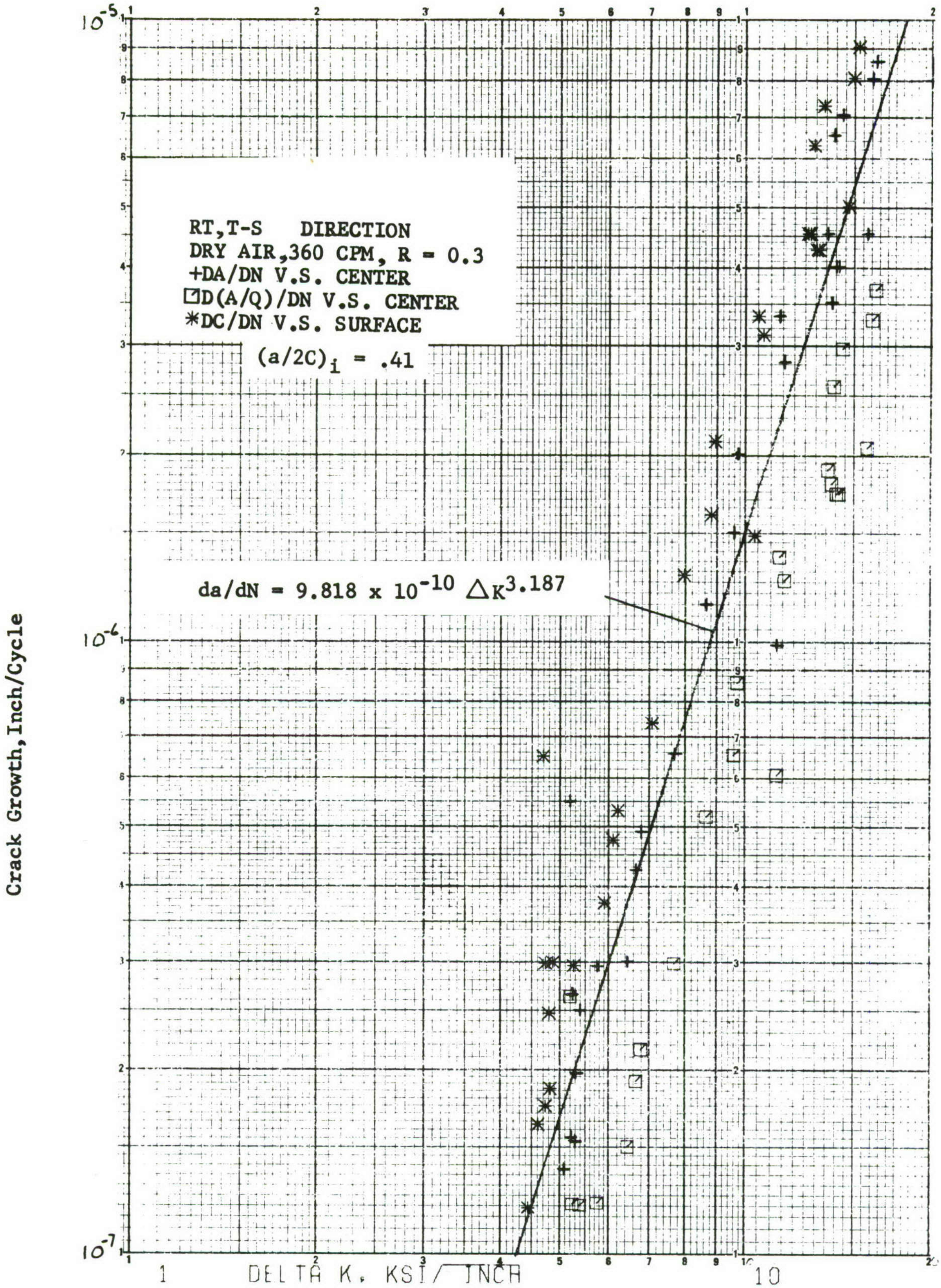


Figure 120 Surface Flaw Specimen TI-8MO-8V-2FE-3AL 8-39

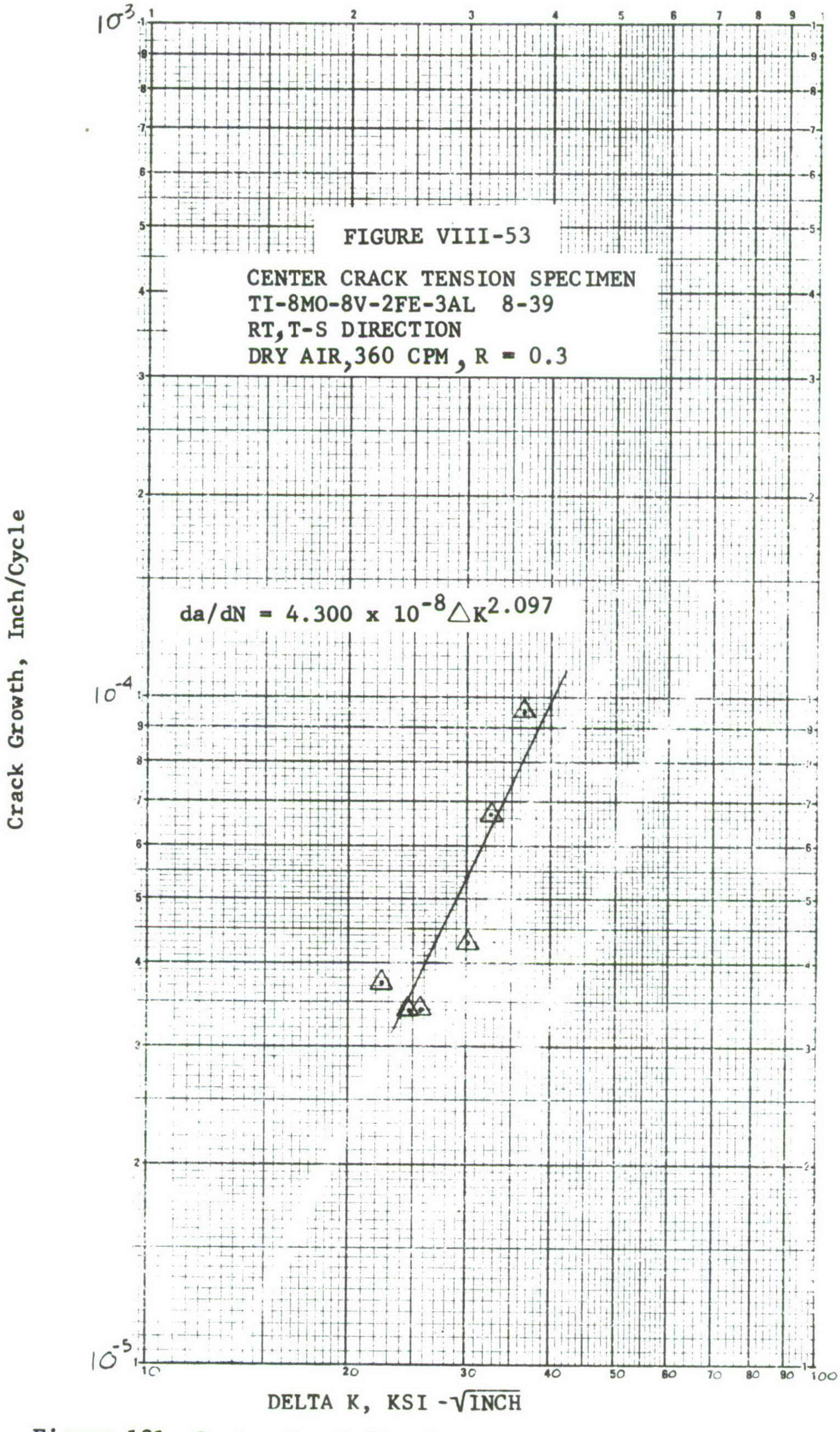


Figure 121 Center Crack Tension Specimen TI-8MO-8V-2FE-3AL 8 39

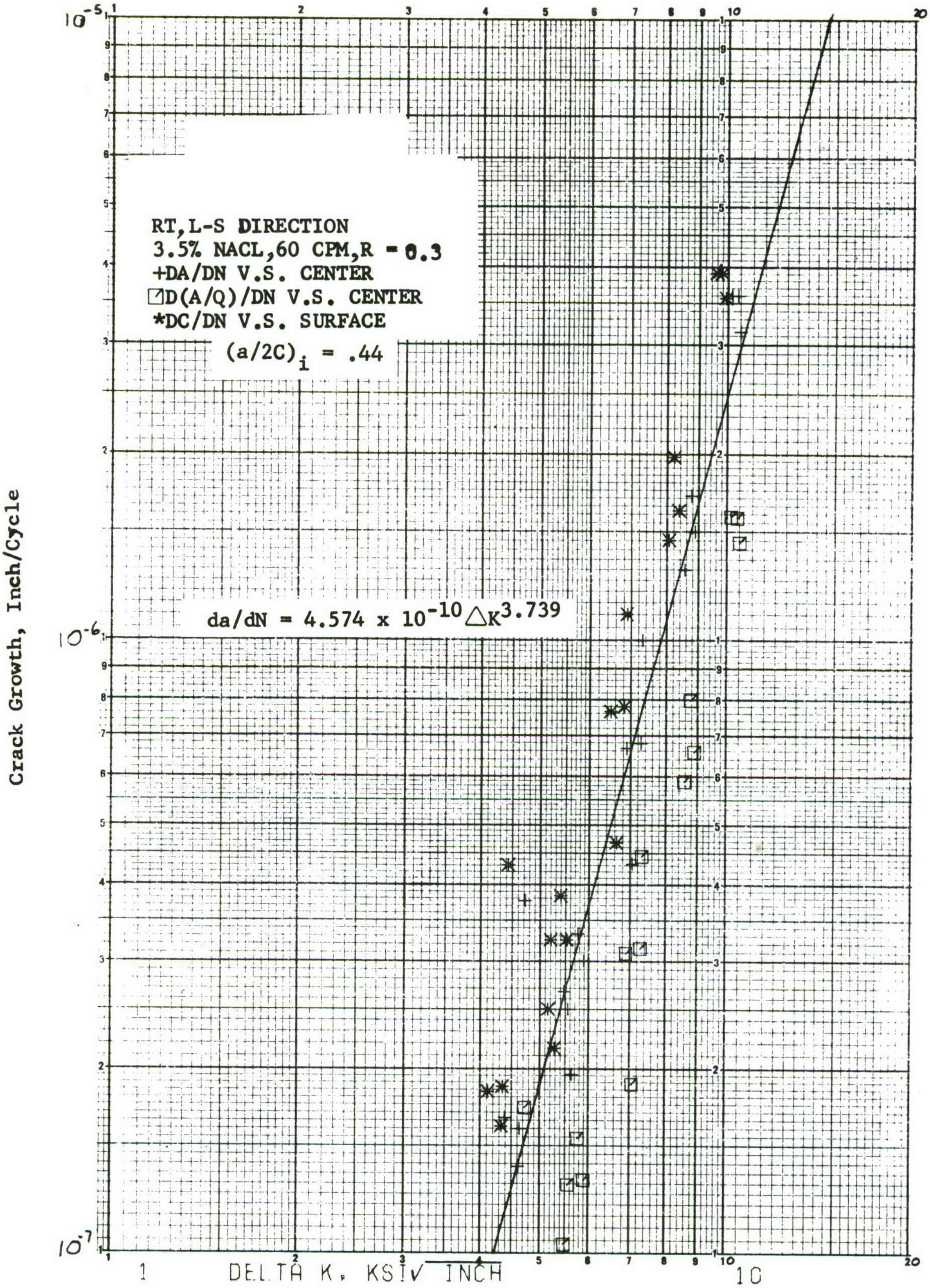


Figure 122 Surface Flaw Specimen TI-8MO-8V-2FE-3AL 8-19

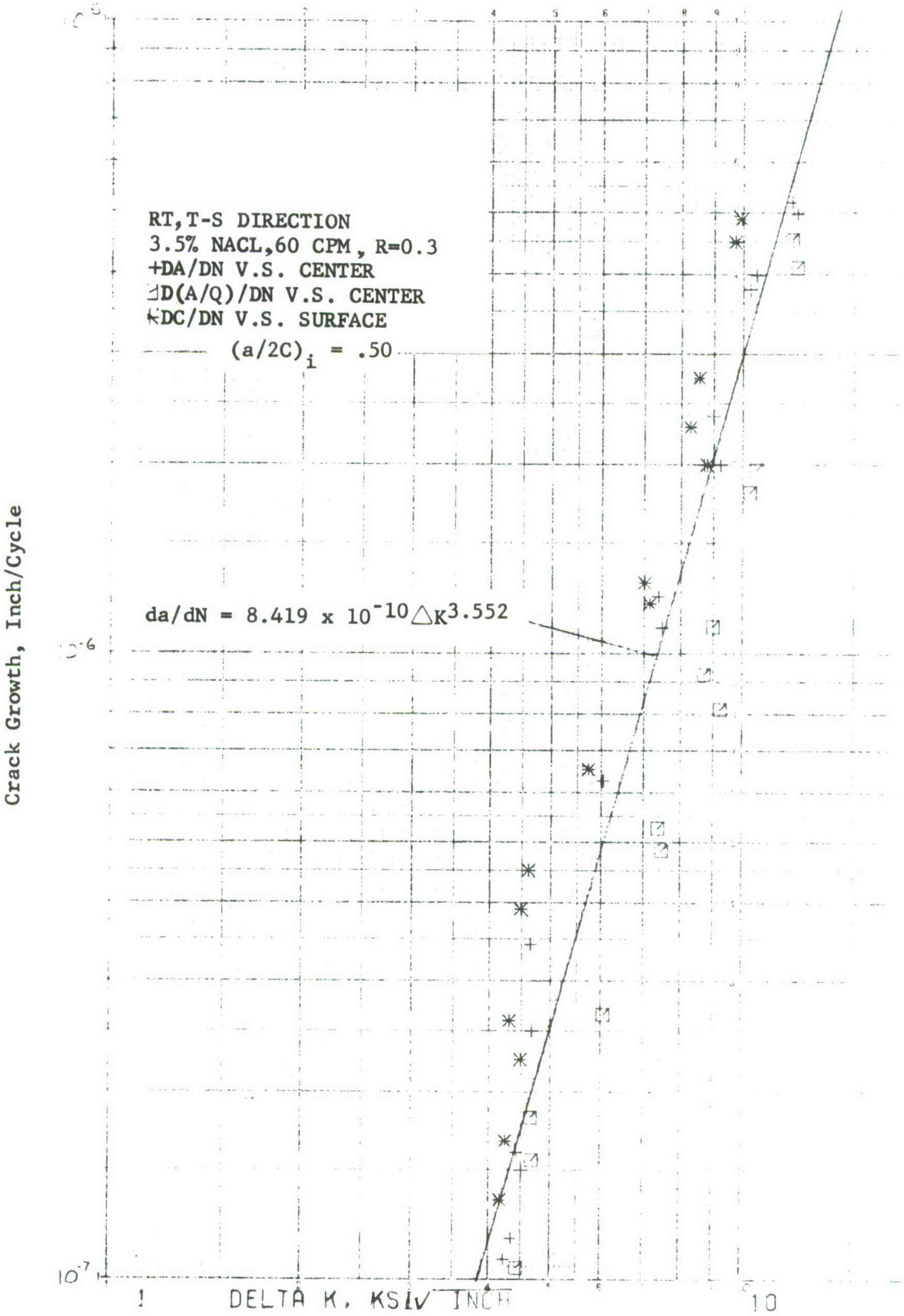


Figure 123 Surface Flaw Specimen TI-8MO-8V-2FE-3AL 8-38

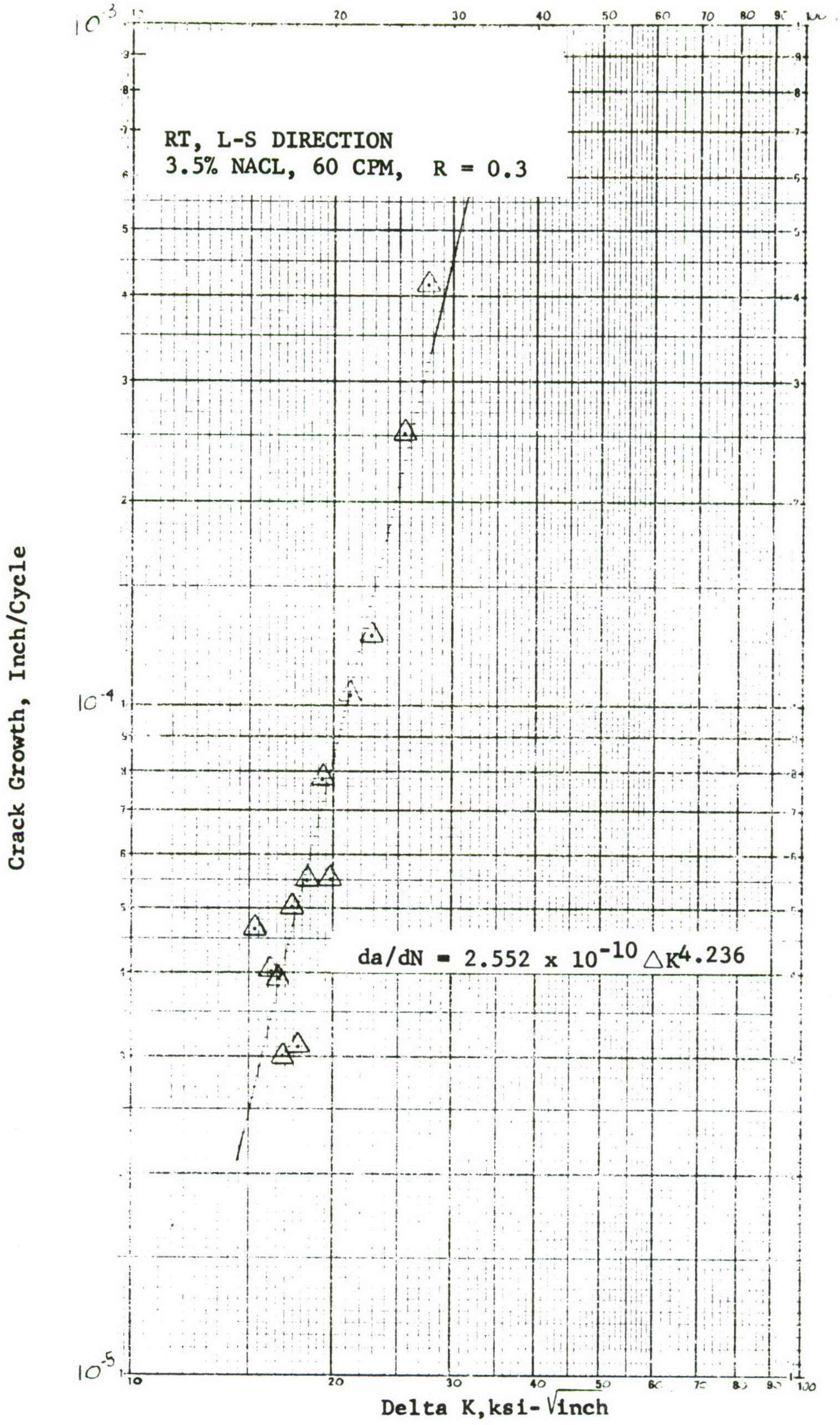


Figure 124 Center Crack Tension Specimen

TI-8MO-8V-2FE-3AL 8-19

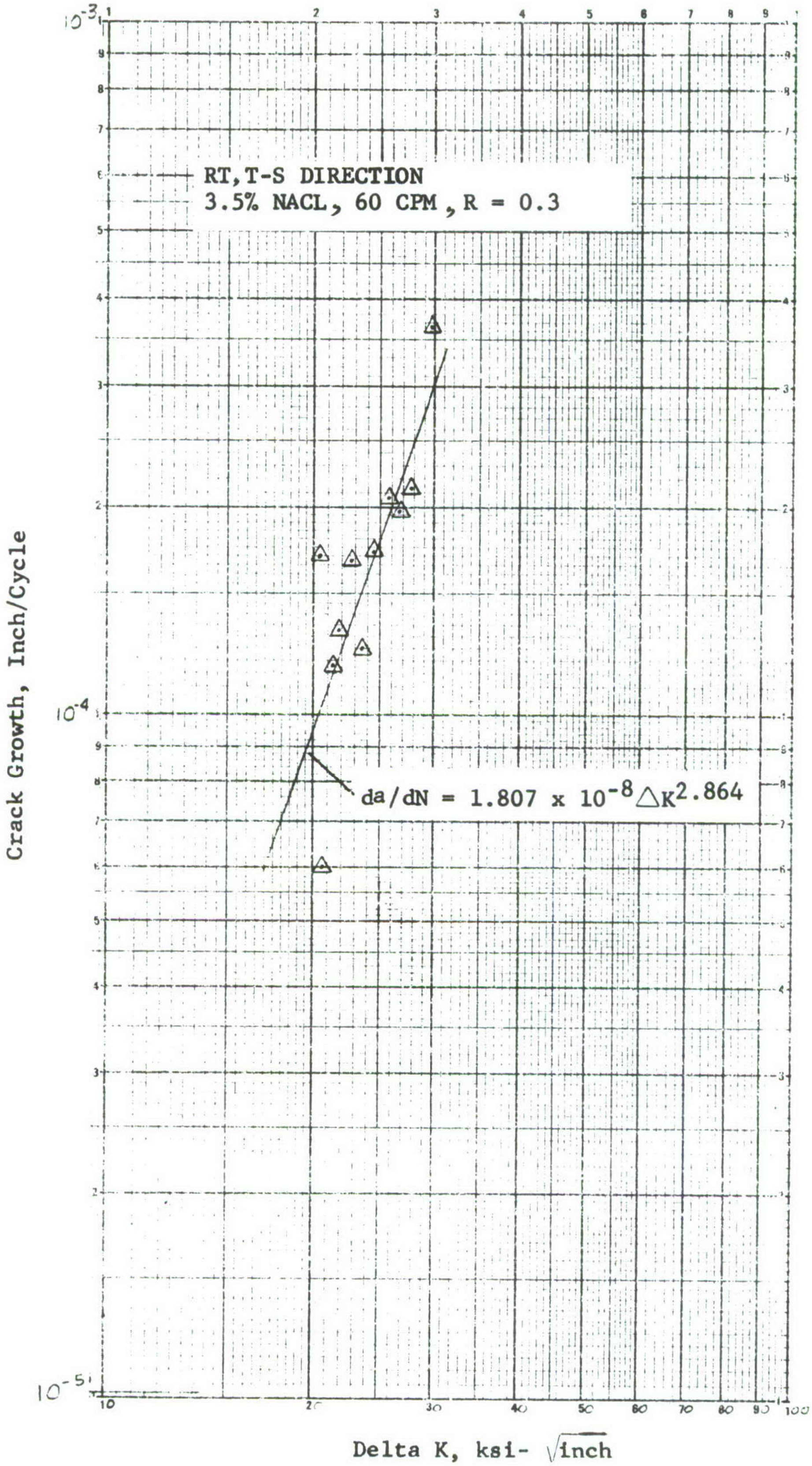


Figure 125 Center Crack Tension Specimen TI-8MO-8V-2FE-3AL 8-39

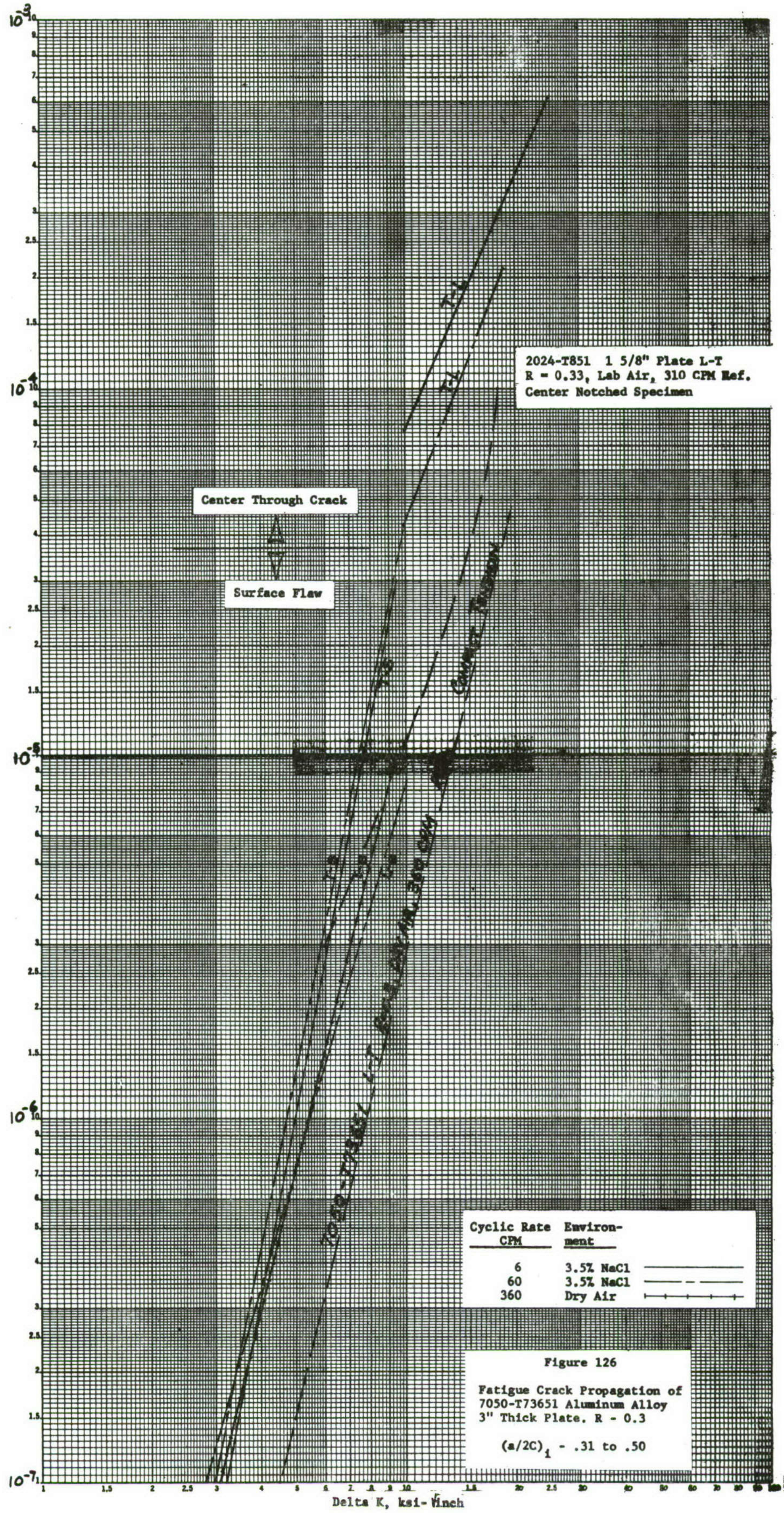


Figure 126

Fatigue Crack Propagation of 7050-T73651 Aluminum Alloy 3" Thick Plate. R - 0.3

$(a/2C)_i$ - .31 to .50

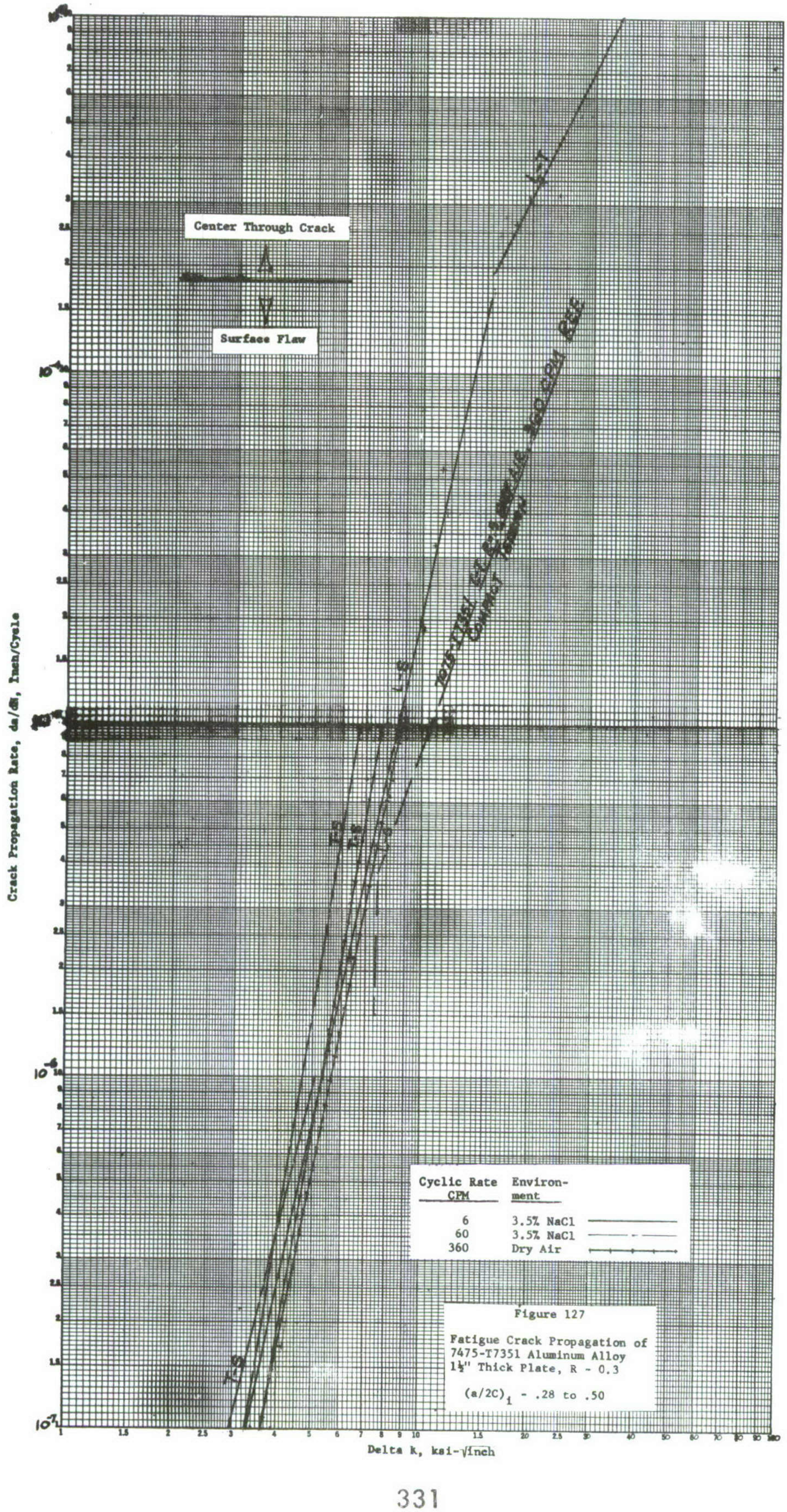
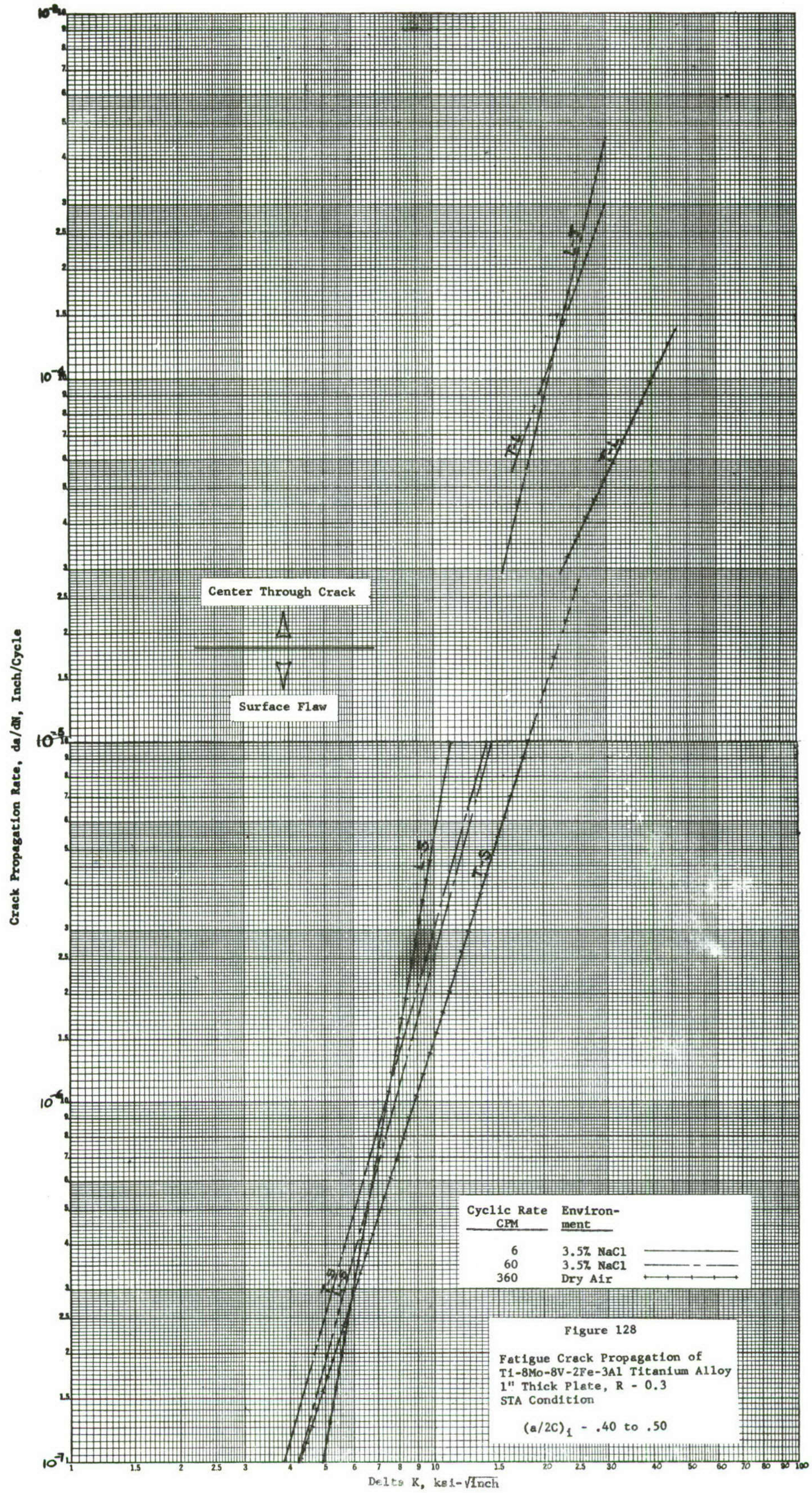


Figure 127

Fatigue Crack Propagation of 7475-T7351 Aluminum Alloy 1½" Thick Plate, R - 0.3

$(a/2C)_1$ - .28 to .50


Center Through Crack
Surface Flaw
Crack Propagation Rate, da/dN, Inch/Cycle
Delta K, ksi-√Inch
Cyclic Rate CPM
Environment
6
3.5% NaCl
60
3.5% NaCl
360
Dry Air
Figure 128
Fatigue Crack Propagation of Ti-8Mo-8V-2Fe-3Al Titanium Alloy 1" Thick Plate, R - 0.3 STA Condition
(a/2C)i - .40 to .50

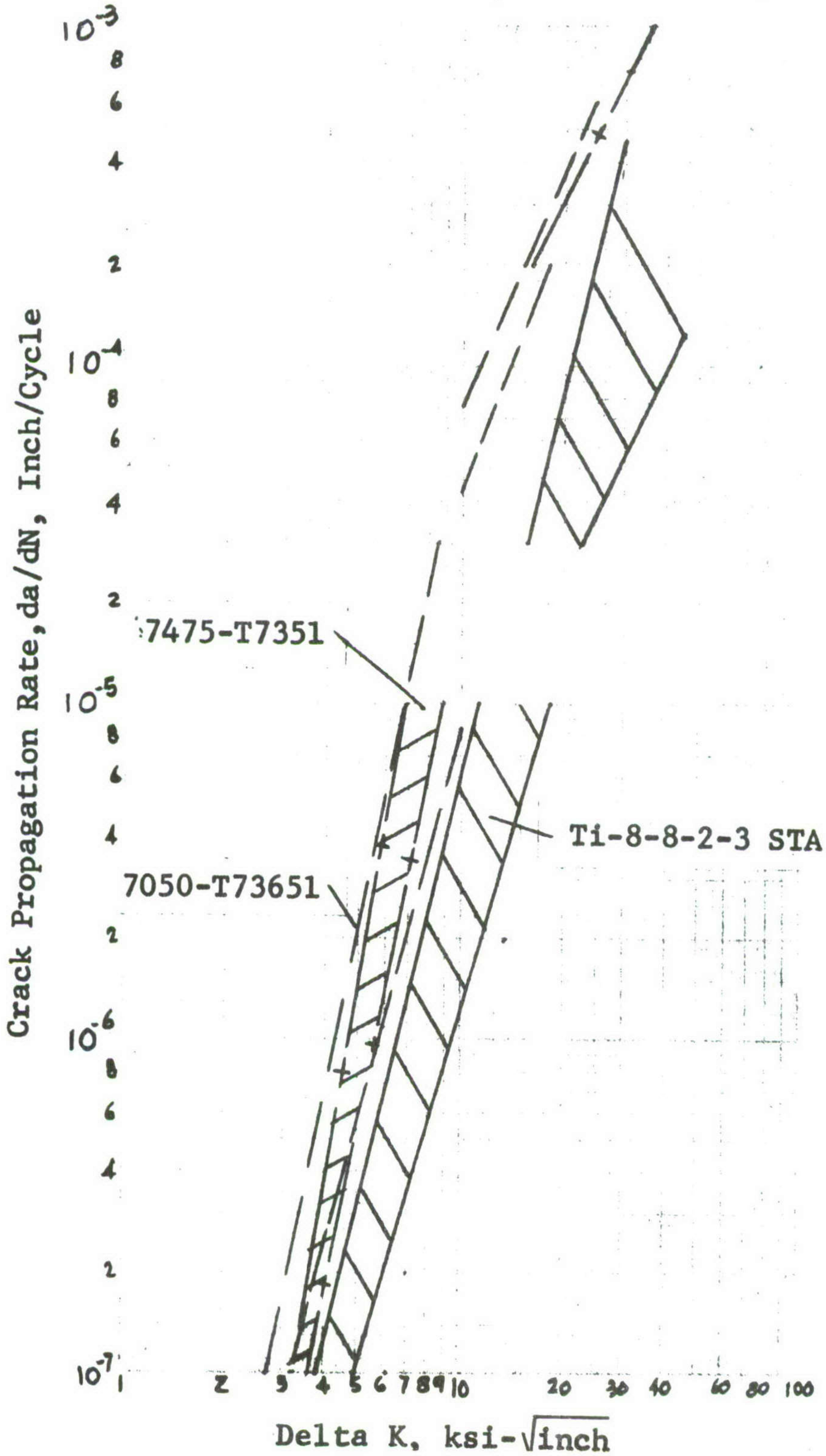
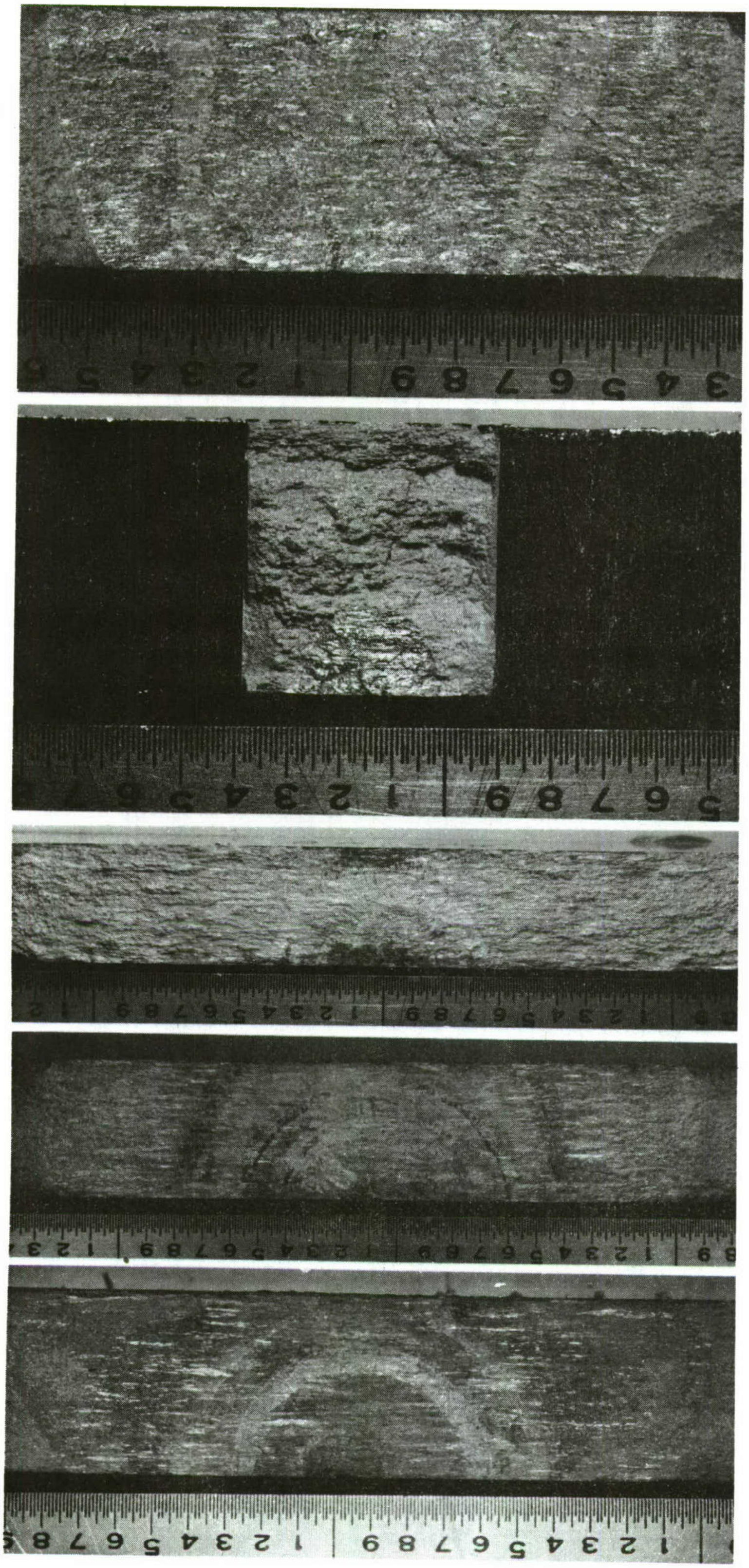


Figure 129 Comparison of Fatigue Crack Growth Rates of 7050-T73651, 7475-T7351 and Ti-8-8-2-3 STA Plates, R = 0.3



Spec. No. 50-44
Dry Air
360 CPM
L-S Direction

(Premature failure from back side crack.)

Spec. No. 50-49
Dry Air
360 CPM
T-S Direction

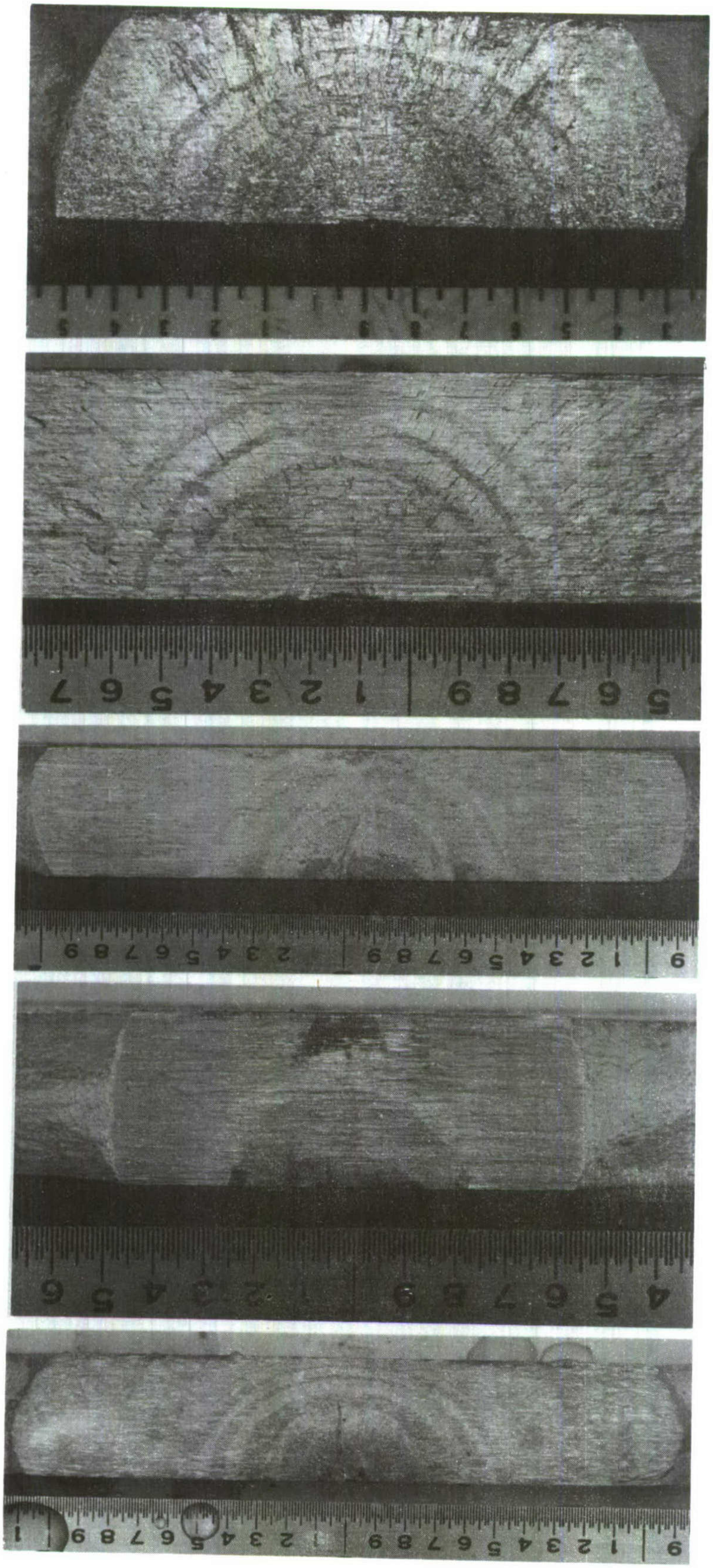
(Premature failure from side crack.)

Spec. No. 50-45
3.5% NaCl 60 CPM
L-S Direction

Spec. No. 50-50
3.5% NaCl 60 CPM
T-S Direction

Spec. No. 50-51
3.5% NaCl 6 CPM
T-S Direction

Figure 130 Fracture Surfaces of 7050-T73651 da/dN Surface Flaw Specimens



Spec. No. 75-23
Dry Air
360 CPM
L-S Direction

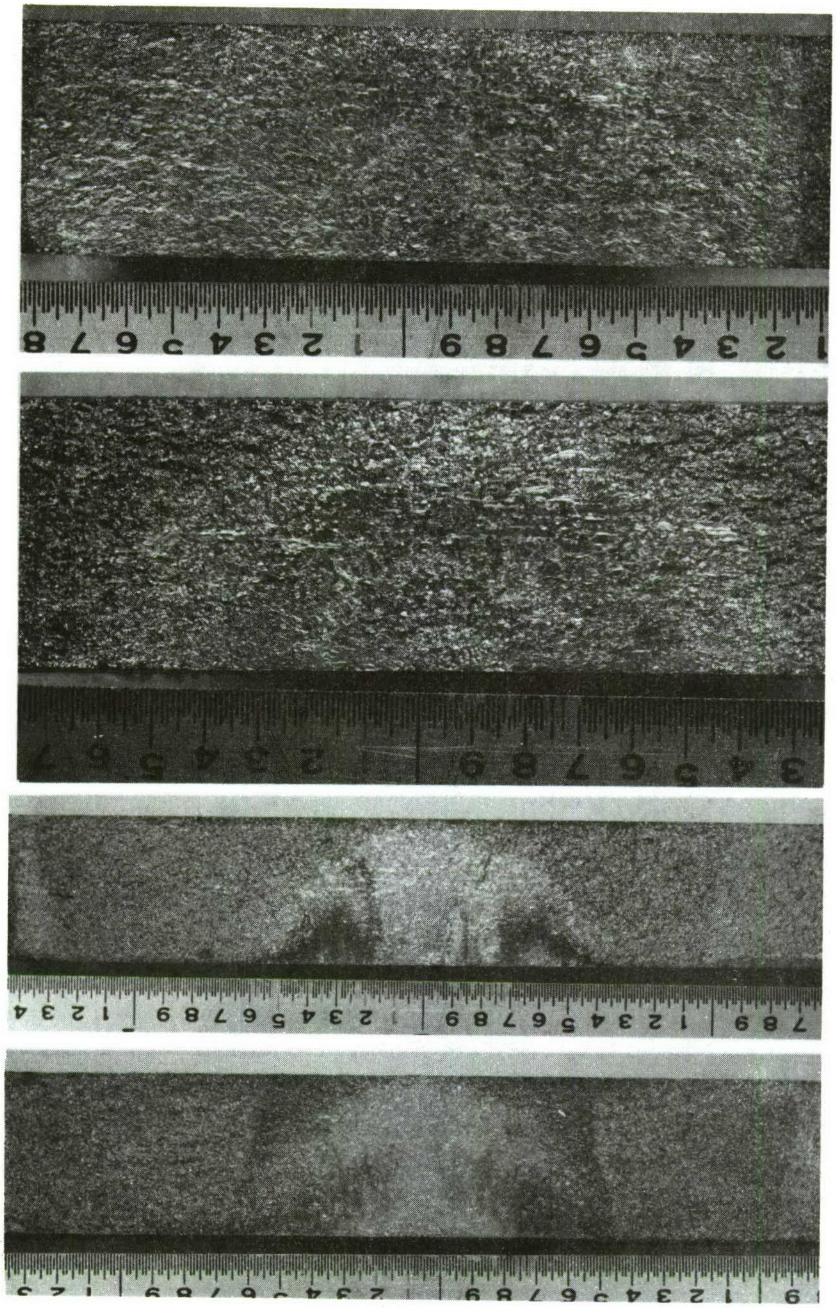
Spec. No. 75-21
Dry Air
360 CPM
T-S Direction

Spec. No. 75-19
3.5% NaCl
60 CPM
T-S Direction

Spec. No. 75-20
3.5% NaCl
60 CPM
T-S Direction

Spec. No. 75-25
3.5% NaCl
6 CPM
L-S Direction

Figure 131 Fracture Surfaces of 7475-T7351 da/dN Surface Flaw Specimens



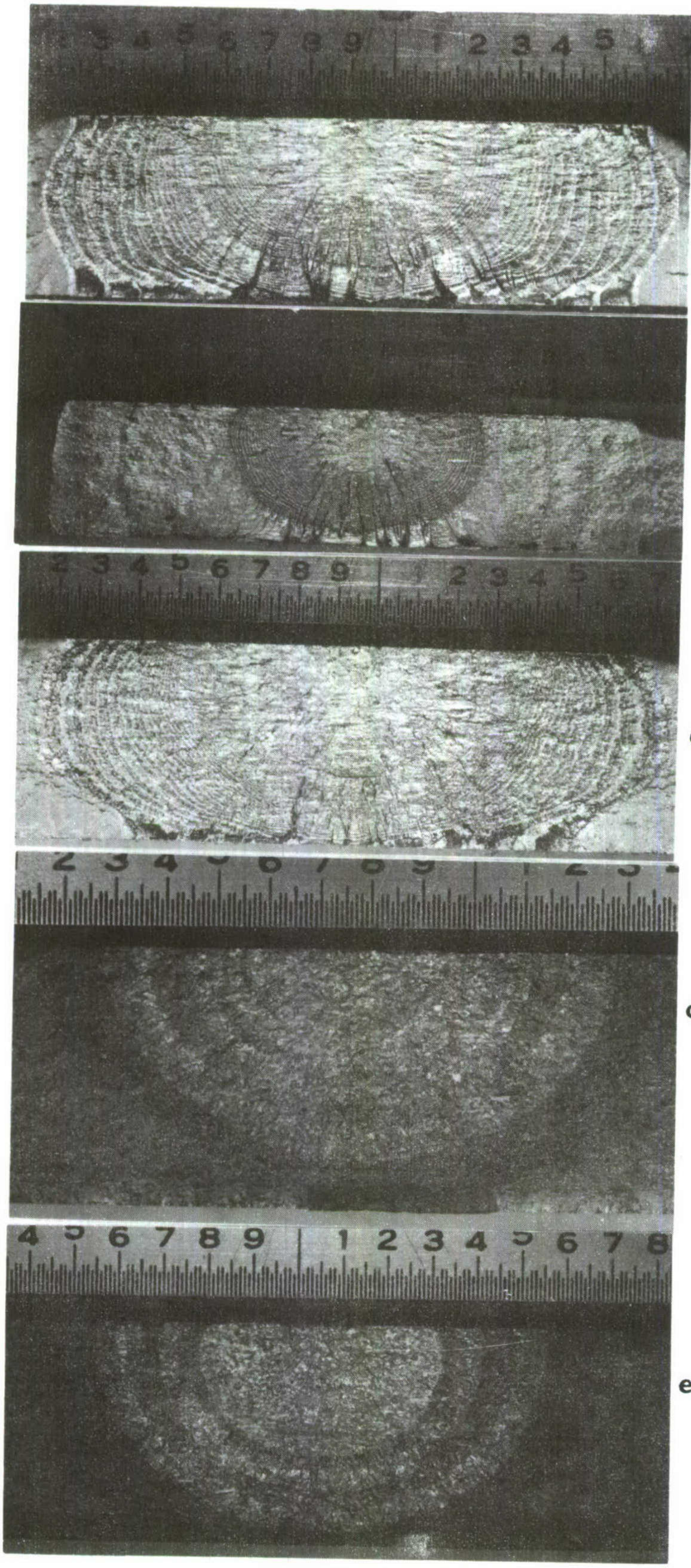
Spec. No. 8-17
Dry Air
360 CPM
L-S Direction

Spec. No. 8-39
Dry Air
360 CPM
T-S Direction

Spec. No. 8-19
3.5% NaCl 60 CPM
L-S Direction

Spec. No. 8-38
3.5% NaCl 60 CPM
T-S Direction

Figure 132 Fracture Surfaces of Ti-8Mo-8V-2Fe-3Al da/dN Surface Flaw Specimens



σ_{max} = 25.2 ksi
$2C_o$ = .310, a_o = .190
Failed in Block 59

a. 7475-T7351
Spec. #75-24

σ_{max} = 25.2 ksi
$2C_o$ = .308, a_o = .213
Failed in Block 48

b. 7475-T7351
Spec. #75-26

σ_{max} = 25.2 ksi
$2C_o$ = .300, a_o = .188
Failed in Block 84

c. 7050-T73651
Spec. #50-48

σ_{max} = 68 ksi
$2C_o$ = .400, a_o = .162
Failed in Block 2

d. Ti-8-8-2-3 STA
Spec. #8-16

σ_{max} = 68 ksi
$2C_o$ = .328, a_o = .255
Failed in Block 4

e. Ti-8-8-2-3 STA
Spec. #8-18

Figure 133 Fracture Surfaces of Spectrum Fatigue da/dN Surface Flaw Specimens

REFERENCES

The following reference documents contain information pertinent of F-111 flight test wing loads.

1. FZS-12-1039, Volume I, "F-111A 100% Flight Loads Program Results, Volume I - Balanced Symmetric Maneuver and Miscellaneous Component Loads Without External Stores", submitted under Contract AF33(657)-8260.

2. FZC-12-082A, "F-111A Detailed Category I Flight Test Plan for Structural Integrity", submitted under Contract AF33(657)-8260.

3. MRTP-12-529, "F-111A No. 13 and No. 75 Structural Integrity Flight Test Program Instrumentation", submitted under Contract AF 33(657)-8260.

4. NACA Report No. 1178, "Calibration of Strain Gauge Installations in Aircraft Structures for the Measurement of Flight Loads".

5. SFPG-12-13, "Detail Procedures for the Calibration of F-111A No. 13 Flight Loads Instrumentation", submitted under Contract AF33(657)-8260.

6. FZS-12-202, "F-111A No. 13 Flight Loads Survey Strain Gage Instrumentation Calibration", submitted under Contract AF33(657)-8260.

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13. ABSTRACT

This report describes the preliminary design and analysis for an Advanced Air Superiority Fighter Stores Loaded, Wet Wing Structure. The wing box of the F-111F airplane designed by the Convair Aerospace Division of General Dynamics was used as the baseline vehicle.

A unique design methodology was followed to arrive at three configurations which offer an optimum balance between structural efficiency and technological advancement. This methodology consists of compiling element concepts; integrating them into cross-section drawings; optimizing them in analytical assemblies; and finally preparation of full wing box designs. Each step was followed with a detailed evaluation and ranking step which utilized a formal merit rating system. This system permitted the evaluation of numerous concepts and insured that each technical discipline participated in the design selection.

A subsequent program is proposed to evaluate the capability of the selected design to meet the overall program goals of advancing technology without significantly affecting costs. The subsequent program involves additional preliminary design, a development test program, detail design, manufacture, and tests; including static, fatigue, and damage tolerance testing. Information generated during this effort will be disseminated to the Air Force and industry in general through an intensive information transfer effort.

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Stress Analysis						
Fatigue						
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Materials						
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Value Engineering						
Manufacturing Engineering						
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